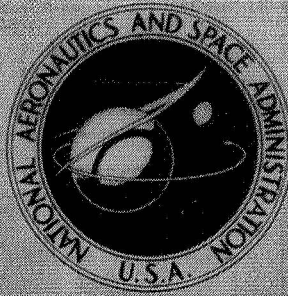


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**NUCLEAR-POWERED AIR-CUSHION
VEHICLES FOR TRANSOCEANIC COMMERCE**

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NUCLEAR-POWERED AIR-CUSHION VEHICLES FOR TRANSOCEANIC COMMERCE

by Frank E. Rom and Charles C. Masser
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SUMMARY

Large air-cushion vehicles (ACV's), greater than 3620 metric tons (4000 tons) gross weight, have the potential for hauling transoceanic cargo at rates in the range of \$0.006 to \$0.012 per metric ton-kilometer (\$0.010 to \$0.020/ton-n mi) at speeds of 185 kilometers per hour (100 knots). It theoretically would take a fleet of over 1000 10 000-metric-ton-gross-weight ACV's to handle 10 percent of the world transoceanic trade projected for 1985. ACV's using compact lightweight nuclear reactors show clearly superior performance for ranges of 3710 kilometers (2000 n mi) or greater. For a range of 7420 kilometers (4000 n mi) the total operating cost for chemical ACV's is three times that for nuclear ACV's. The nuclear ACV performance is less sensitive than the chemical ACV to the operating and cost assumptions used. Relatively large variations in any of the important assumptions had a relatively small effect on nuclear ACV performance.

INTRODUCTION

The world is currently experiencing a major expansion in transoceanic trade. The Department of Transportation predicts that world dry cargo ocean trade will double by 1980 (ref. 1), as shown in figure 1. In 1980, world ocean trade is forecast to be 3.7 billion metric tons. This represents about 12 trillion metric ton-kilometers (20 trillion ton-n mi) of ocean commerce per year. A large portion of this trade is of sufficient value to make it worth shipping at \$0.006 to \$0.012 per metric ton-kilometer (\$0.01 to \$0.02/ton-n mi). In 1968, about 11.5 percent of all U.S. foreign trade was liner tonnage that had an average value of \$0.626 per kilogram (\$0.284/lb) (see ref. 2). Assume that 10 to 15 percent of cargo value is a reasonable cost for transportation and that 7420 to 11 130 kilometers (4000 to 6000 n mi) is an average transoceanic range. This assumption

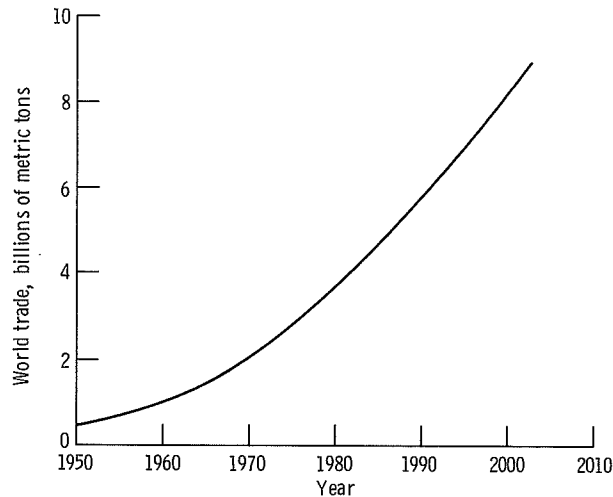


Figure 1. - Department of transportation world oceanborne trade forecast.

yields an allowable charge of \$0.006 to \$0.012 per metric ton-kilometer (\$0.01 to \$0.02/ton-n mi) for cargo whose value is \$0.55 to \$0.66 per kilogram (\$0.25 to \$0.30/lb). In other words, there may be more than 1.2 trillion metric ton-kilometers (2 trillion ton-n mi) of cargo traffic suitable for hauling at \$0.006 to \$0.012 per metric ton-kilometer (\$0.01 to \$0.02/ton-n mi) in 1980. This low cost of transoceanic commerce is comparable to railroad costs for overland movement of cargo.

If air-cushion vehicles could be developed to carry cargo at \$0.006 to \$0.012 per metric ton-kilometer (\$0.01 to \$0.02/ton-n mi) at a speed of 185 kilometers per hour (100 knots), it would take a fleet of more than 1000 such vehicles that have a cargo capacity of 4530 metric tons (5000 tons) each to handle the traffic. These figures do not take into account the additional traffic that would be attracted by the large reduction in transit time resulting from the 185-kilometer-per-hour (100-knot) speed. There is, therefore, clearly an incentive to determine whether air-cushion vehicles can be developed to carry cargo at a rate of \$0.006 to \$0.012 per metric ton-kilometer (\$0.01 to \$0.02/ton-n mi).

NASA has been conducting a low-level study to determine the feasibility of large, nuclear-powered, air-cushion vehicles and aircraft. The objectives of the study are (1) to determine the feasibility of practical, safe, and economical nuclear powerplants for air-cushion vehicles (ACV) and aircraft, (2) to define the key problems requiring research and development, and (3) to demonstrate or develop key technology that is required for feasibility assessment.

This report presents the results of a simplified preliminary study to determine the potential of air-cushion vehicles for achieving cargo rates of \$0.006 to \$0.012 per metric ton-kilometer (\$0.01 to \$0.02/ton-n mi). Both chemical and nuclear power are considered. The nuclear-powered vehicles use the propulsion technology that is being studied

or developed in the NASA study (ref. 3). Chemical vehicles use gas turbine technology forecast for 1980.

Because of the large number of performance and cost variables for which assumptions must be made, the results must be carefully considered in light of the assumptions made. To facilitate the evaluation of the sensitivity of the results to the assumptions, each major assumption is independently varied and the effect on operating cost presented.

VEHICLE DESCRIPTION

This section describes the air-cushion vehicles that are considered in the report. The vehicles are characterized by their lift-drag ratios and weight breakdowns. The propulsion systems studied are gas turbine systems using shrouded propellers. The energy sources considered are chemical (jet fuel) and nuclear.

Vehicle Characteristics

The air-cushion vehicle has been pioneered by the British. The SRN-4 hovercraft, which is presently the world's largest (152 metric tons (168 tons) gross weight), has been in commercial service for several years. Several of these vehicles operate as ferries across the English Channel. Figure 2 shows a SRN-4 in operation. Many smaller air-

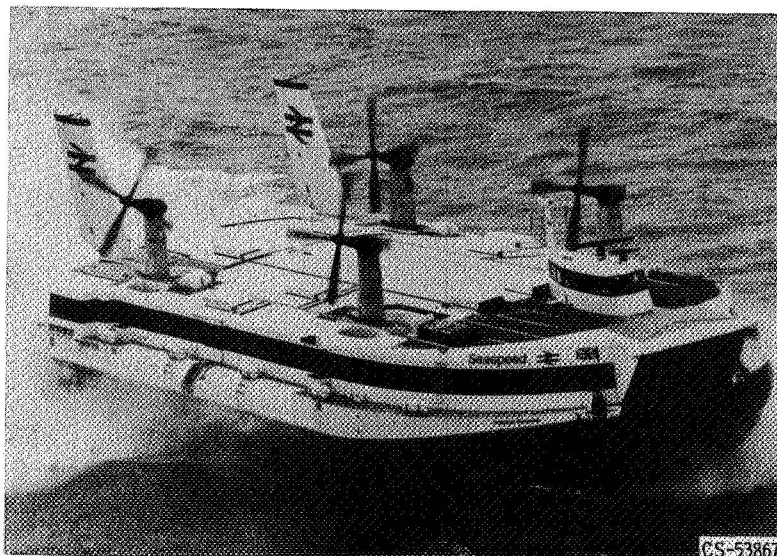


Figure 2. - British Hovercraft Ltd, SRN-4 air-cushion vehicle in operation as a passenger and automobile ferry. Gross weight, 152 metric tons (168 tons); speed, 120.5 kilometers per hour (65 knots).

cushion vehicles have been used for military operations and other ferry services. Currently, two 90.6-metric-ton (100-ton) air-cushion vehicles are being constructed in the United States for the Joint Surface Effect Ships Program Office (JSESPO), a combined agency of the Navy and the Department of Interior's Maritime Administration. One, shown in figure 3, is being constructed by Aerojet and the other, shown in figure 4, by Bell Aerosystems. They are designed to operate at speeds approaching 167 kilometers per hour (90 knots). Both these vehicles are test craft that are expected to begin sea trials in 1971. They are intended to yield design and performance data that will serve as a basis for the design and development of much larger air-cushion vehicles with gross weights of 3620 to 4530 metric tons (4000 to 5000 tons) that will operate at speeds greater than 185 kilometers per hour (100 knots).

The lift-drag ratios of the air-cushion vehicles used for this analysis are shown in figure 5. The lift-drag ratio (L/D) is plotted as a function of vehicle speed in knots. The L/D includes the drag equivalent of the power that is necessary to maintain the cushion of air beneath the vehicle. Air escapes from beneath the skirts that trap the air to maintain the cushion of air that supports the vehicles. The upper bound is an optimistic curve that applies for vehicles of several thousand metric tons. The lower bound is a more pessimistic curve that applies for vehicles of about 1000 metric tons. The solid curve is a median curve that is used as a reference value for this analysis. It should be noted that this curve does not distinguish between the various types

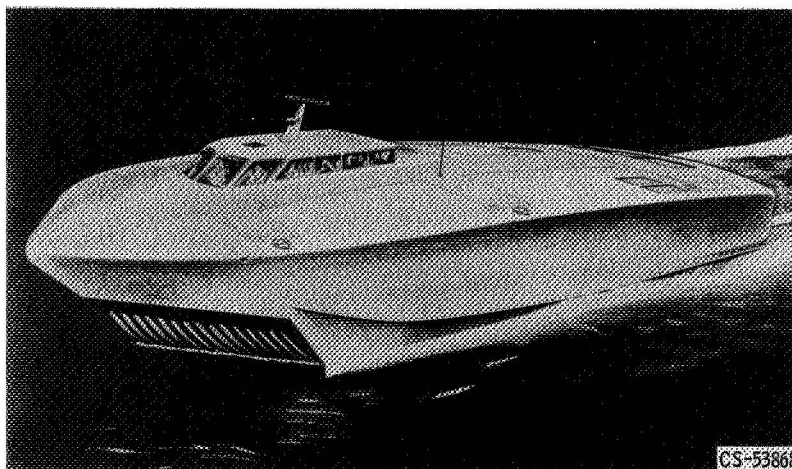


Figure 3. - Aerojet air-cushion vehicle under construction for the Joint Surface Effect Ships Program Office (JSESPO). Gross weight, 90.6 metric tons (100 tons); speed, 167 kilometers per hour (90 knots).

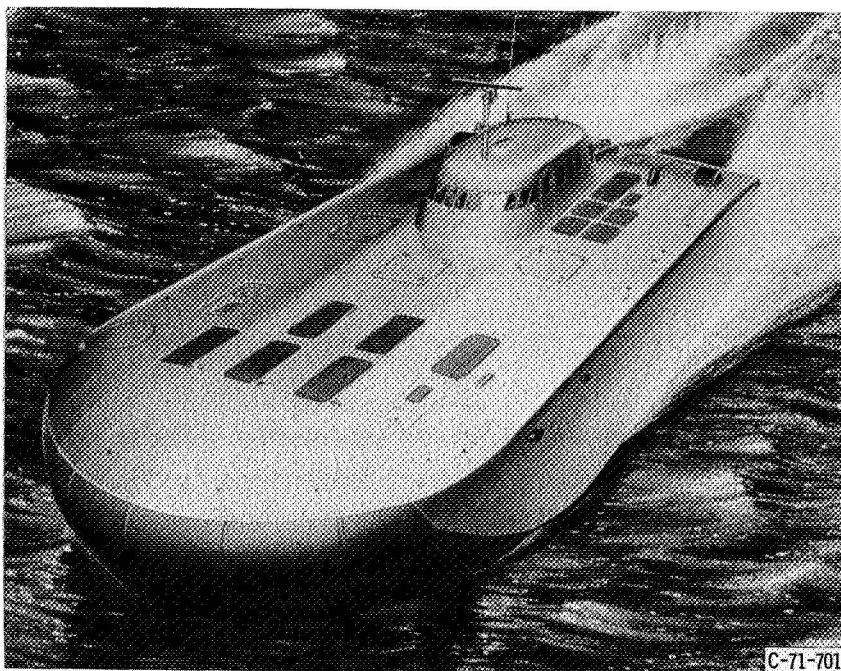


Figure 4. - Bell Aerosystem air-cushion vehicle under construction for the Joint Surface Effect Ships Program Office (JSEPO). Gross weight, 90.6 metric tons (100 tons); speed, 167 kilometers per hour (90 knots).

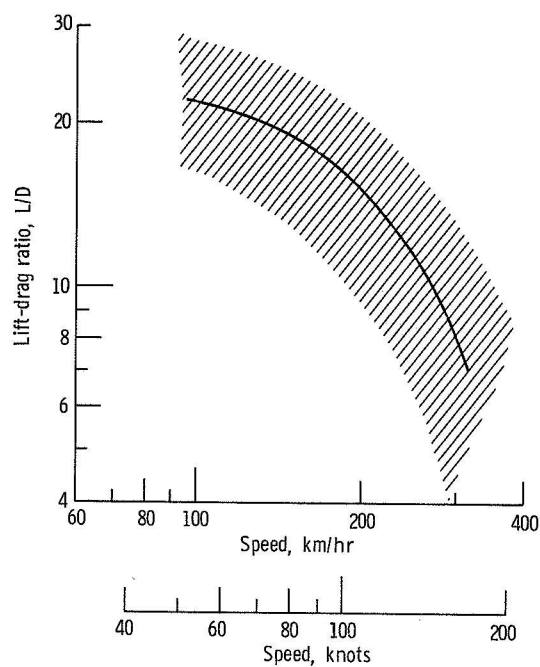


Figure 5. - Lift-drag ratios for air-cushion vehicles.

of air-cushion vehicles. Some vehicles have sidewalls that penetrate into the water so that cushion seals are required only at the bow and stern. The 90.6-metric-ton (100-ton) JSESPO vehicles (figs. 3 and 4) are examples of this type. Some vehicles have skirts all around their perimeter so that there is no structure in the water at all. The SRN-4 (fig. 2) is an example of this type. The L/D curve used for this analysis is therefore typical of ACV as a class. Further study could be made to distinguish between various types of ACV, but this was beyond the scope of this report.

Propulsion System Characteristics

Gas turbine engines were assumed for the air-cushion vehicle propulsion. The system consists of a prop-fan (shrouded propeller) driven by a turboshaft engine. The prop-fan yields a high thrust per unit shaft power without the extreme diameter required with propellers. Greatly simplified performance data are used in this study to facilitate parametric analysis.

In the case of nuclear power, it was assumed that the reactor was of a high-pressure helium-type, as shown in figure 6. The helium is heated as it flows between the hot reactor fuel elements. The helium is then ducted to a heat exchanger that is located between the compressor and combustor of a turboshaft engine. The figure shows a turbofan engine. The air flowing from the compressor is heated by the heat exchanger. The engine can run on either nuclear or chemical power in this arrangement. Shielding and a containment vessel are shown surrounding the reactor. The shielding is complete (unit or 4π shielding) so that dose levels are the same in all directions from the reactor shield. The design radiation dose level at 9.15 meters (30 ft) from the reactor centerline is 0.25 millirem per hour. At this location it would take a continuous exposure of 2000 hours (a 200 000-mile trip) to receive the normal dose received on Earth due to natural causes (125 millirem per year) in a year. Beyond 9.15 meters (30 ft) from the reactor centerline the dose falls off approximately as the square of the distance. At 30.5 meters (100 ft) the dose rate is 0.025 millirem per hour. It would take 20 000 hours to receive the normal yearly natural dose on Earth in this case. In actual practice the dose levels will be even less than the values used here because other materials (such as structure, cargo, equipment, etc.) that exist between the shield and the dose-measuring point provide shielding but are not included in the calculation.

An important feature of the reactor design is that a containment vessel is provided. The containment vessel is designed to prevent the escape of fission products in the worst impact accident, and also in the event of a reactor meltdown that follows a major accident. Descriptions and results of experiments on the principles used to achieve fission product containment are discussed in references 3 to 7. A brief description of the prin-

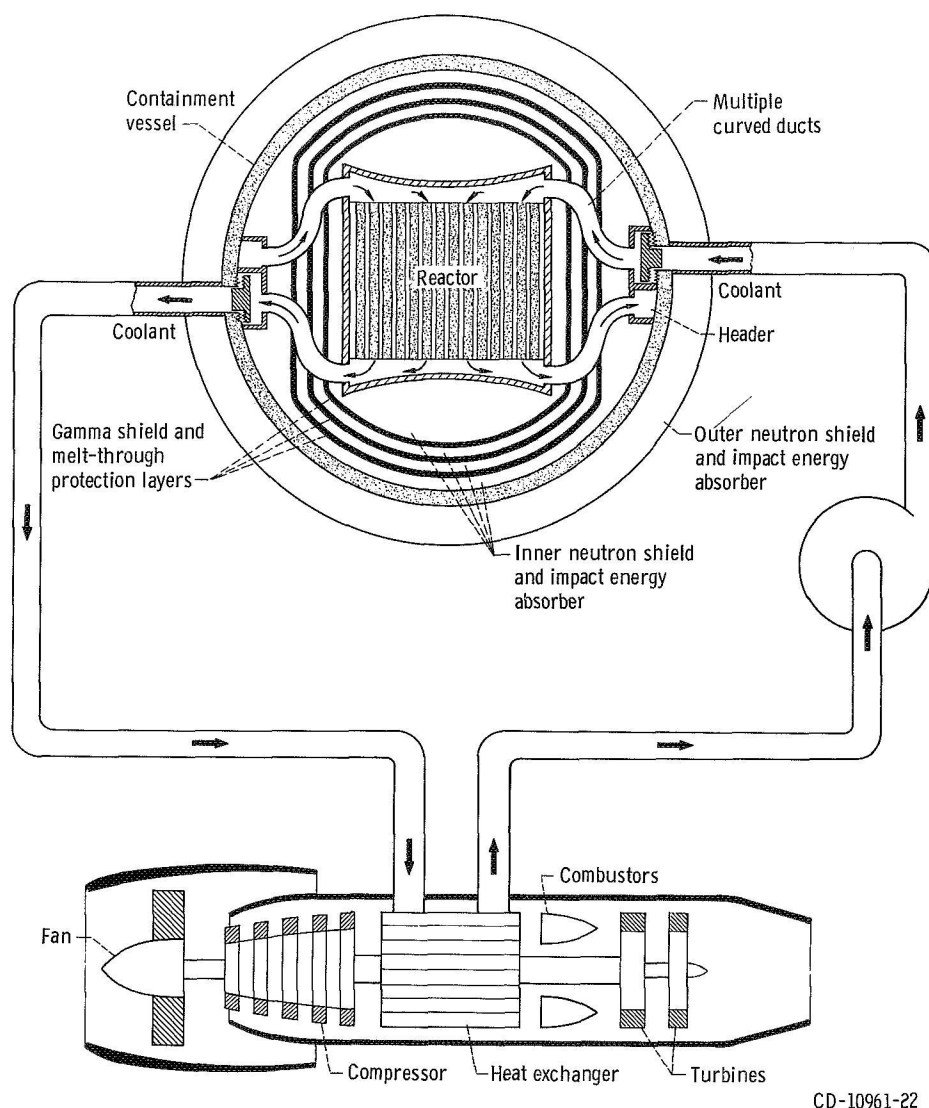


Figure 6. - Schematic drawing of a helium-cooled reactor for mobile applications.

ciples involved is included here because this represents a departure from commonly used concepts of fission product containment.

The particular system shown in figure 6 was specifically designed for subsonic aircraft where impact speeds could be as high as 305 meters per second (1000 ft/sec). Similar principles would apply for the lower speed range of air-cushion vehicles. The ACV impact problem, however, is almost trivial compared to the aircraft impact problem. The ACV velocity is much lower and, because impact energy varies as the square of the velocity, the impact energy to be absorbed is more than an order of magnitude less. In addition, because the ACV operates on the earth's surface, the direction from which impacts can occur is limited to those in a plane rather than in three-dimensional space as for aircraft.

The containment vessel and reactor vessel are designed to prevent rupture at high impact speeds. This is accomplished by several design features. First of all, the containment and reactor vessels are fabricated of a ductile high-strength material such as stainless or maraging steel. High-strength, very ductile materials are used so that the kinetic energy of impact is absorbed by plastic deformation without rupture. Secondly, the outer and inner shields are fabricated of materials that are formed so as to absorb energy by their deformation during impact. Honeycomb structure or small spheres are examples of shapes that will absorb energy as they are deformed during impact. The neutron shield external to the containment vessel is fabricated of plastic honeycomb. The gamma shielding required in addition to the shielding provided by the reactor and containment vessels is fabricated of small deformable pieces of depleted uranium metal. The small pieces are designed to provide the proper volume fraction required for minimum weight shield and also to provide energy absorption capability when they are deformed during impact. The void remaining when the shielding space is filled with the uranium metal pieces is filled with water for neutron shielding. The water may also serve as an aid for absorbing kinetic energy. The high water pressures that are generated during impact could serve to expand or stretch the containment vessel so that a greater weight fraction of the vessel is used to absorb energy. The basic feature of the reactor system design is that it utilizes as much of the system materials as possible to serve multiple functions. For example, the containment vessel and reactor vessel serves as a shield, structure, and energy absorber besides providing the basic containment functions.

To provide for retention of fission products during a reactor meltdown, two situations must be considered. One is meltdown without impact and the other is meltdown after impact. To provide for the case of meltdown without impact (such as a loss-of-coolant accident), a layer of UO_2 pebbles is located just inside the reactor vessel. The UO_2 bed is a refractory insulating layer that will reduce the heat flow through the containment vessel. This causes the reactor materials and fission products to reach high temperatures without melting through to the reactor vessel. Because the reactor materials (including the wide variety of fission product compounds that are generating heat by their decay) are forced to go to high temperatures, vapors are formed. These vapors diffuse or flow into the UO_2 pebble bed. As the vapors flow down the temperature gradient in the pebble bed, they condense at each vapor's appropriate condensation temperature. The net effect is that the heat-generating fission products tend to condense in relatively uniform concentric layers at each appropriate condensing temperature. This results in a relatively uniform heat flux leaving the reactor vessel. The reactor vessel is immersed in shield water which serves to cool the vessel. The heat causes water to form steam which is released to the atmosphere when the desired shield water pressure has been achieved.

In the case of reactor meltdown after impact, the shield water may or may not be al-

lowed to remain in the system. If it does, meltdown is handled as just described. In the event that no water is present in the shield, another layer of UO_2 pebbles is provided on the inside surface of the containment vessel. When the reactor melts down, the vapors that are formed flow out into the UO_2 layer and are condensed in concentric shells just as discussed previously. The UO_2 is used in this case to achieve as uniform a heat flux as possible around the entire containment vessel. The only means of cooling the containment vessel now, however, is thermal radiation and free convection to the air. This requirement determines the minimum containment vessel size. For a 600-megawatt reactor this corresponds to a diameter of about 6.1 meters (20 ft) if the containment vessel is not to exceed 1030 K (1400° F).

Experimental and analytical studies are underway to determine the feasibility of the principles outlined here. The results to date are given in references 4 and 5.

Inasmuch as the application studied herein is for transoceanic commerce, nuclear safety problems are further minimized. As indicated in reference 6 and 7, postimpact reactor meltdown protection is much simpler to handle for overwater accidents. The design procedures outlined in the preceeding paragraphs to prevent containment vessel rupture due to reactor meltdown can be greatly simplified if the vessel is submerged in water. The containment vessel diameter need be only about one-half the diameter of the air-cooled case. In addition, even if containment vessel rupture occurs under water, only the noble (inert) fission product gases escape because the other fission products are dissolved or trapped in the water.

ANALYSIS

The analysis has two main subdivisions. The first deals with performance estimation in terms of weights, speed, power, and payload. The second deals with a simplified cost analysis used to estimate the operating cost as a function of the operating variables. The analysis presents only the equation and relations used. The specific values used are presented in the following section ASSUMPTIONS. A table listing the values used and the range over which each is varied is at the end of that section. The symbols used in the analysis are defined in the appendix.

Performance Analysis

Gross weight. - The gross weight W_G of the air-cushion vehicle is the sum of all the component weights:

$$W_G = W_{ST} + W_E + W_R + W_{SH} + W_F + W_{PAY} \quad (1)$$

Structure weight. - The structure weight includes the airframe, air-cushion parts, crew, fuel tanks, furniture, and all other parts that cannot be called engine, fuel, reactor, shield, or payload. The structure weight is expressed as a fraction of the gross weight:

$$W_{ST} = \frac{W_{ST}}{W_G} \times W_G \quad (2)$$

Engine weight. - The engine weight is expressed as specific engine weight (lb/shaft power). It includes the turboshaft engine, fans (or shrouded propellers), and nacelles, and the heat exchanger in the case of nuclear engines:

$$W_E = \frac{W_E}{P_S} \times P_S \quad (3)$$

The values for specific engine weight W_E/P_S that are used in the analysis are presented in the section ASSUMPTIONS. If W_G is in metric tons and F in newtons, P_S in kilowatts is determined as follows:

$$P_S(\text{kilowatts}) = \frac{9800 W_G}{\left(\frac{L}{D}\right)\left(\frac{F}{P_S}\right)} \quad (4a)$$

If W_G is in tons and F in pounds force, P_S in horsepower is determined as follows:

$$P_S(\text{horsepower}) = \frac{2000 W_G}{\left(\frac{L}{D}\right)\left(\frac{F}{P_S}\right)} \quad (4b)$$

Specific values for the specific thrust F/P_S are presented in the section ASSUMPTIONS.

Reactor weight. - The reactor weight is defined as the entire mass within the reactor shield. It includes fuel elements, core structure, reflector, control system, reactor vessel, headers, and ducts inside the inner diameter of the shield. The reactor is described simply in terms of weight density ρ_R and power density ρ_P . If ρ_R is in grams per cubic centimeter and ρ_P is in watts per cubic centimeter, the reactor weight in metric tons is

$$W_R(\text{metric tons}) = \frac{\rho_R P_{th}}{\rho_P} \quad (5a)$$

If ρ_R is in pounds per cubic foot and ρ_P is in megawatts per cubic foot, W_R in tons is

$$W_R(\text{tons}) = \frac{\rho_R P_{th}}{2000 \rho_P} \quad (5b)$$

where

$$P_{th}(\text{megawatts}) = \frac{P_S}{\eta} \times 10^{-3} \quad \text{if } P_S \text{ is in kilowatts} \quad (6a)$$

$$P_{th}(\text{megawatts}) = \frac{P_S}{\eta} (7.46 \times 10^{-4}) \quad \text{if } P_S \text{ is in horsepower} \quad (6b)$$

Shield weight. - The shield weight has been computed assuming uniform shielding in all (4π) directions. The dose rate is 0.25 millirem per hour at 9.15 meters (30 ft). The dose rate falls off approximately as the inverse of the square of the distance from the reactor. At 30.5 meters (100 ft) the dose rate is about 0.025 millirem per hour. The shield is composed of optimum-thickness spherical layers of depleted uranium, mixtures of depleted uranium and water, and water. The reactor is assumed to be a sphere whose size is determined by reactor power density and reactor power. The calculated data points have been generalized, and are expressed by the following equation (private communication with M. Wohl of Lewis):

$$W_{SH} = 20.06 B(P_{th})^{0.281-0.0540 \ln(\rho_P)} \quad (7a)$$

if W_{SH} is in metric tons and ρ_P is in watts per cubic centimeter.

$$W_{SH} = 22.06 B(P_{th})^{0.473-0.0540 \ln(\rho_P)} \quad (7b)$$

if W_{SH} is in tons and ρ_P is in megawatts per cubic foot, where B is an arbitrary constant that is normally equal to unity unless a degree of pessimism is desired, in which case B can be assigned any desired value.

Fuel weight. - The fuel weight for chemically powered aircraft, from the Breguet range formula, is

$$W_F = W_G \left(1 - e^{\frac{-9.8 RS}{V(L/D)(F/P_S)}} \right) \quad (8a)$$

where R is flight range in kilometers, S is the fuel consumption in kilograms per hour per kilowatt, V is the speed in kilometers per hour and F/P_S is thrust per shaft power in newtons per kilowatt.

$$W_F = W_G \left(1 - e^{\frac{-RS}{V(L/D)(F/P_S)}} \right) \quad (8b)$$

where R is flight range in nautical miles, S is the fuel consumption in pounds per hour per horsepower, V is the speed in knots, and F/P_S is the thrust per shaft power in pounds per horsepower of the engine used.

Payload. - The payload is found from equation (1):

$$W_{PAY} = W_G - W_{ST} - W_E - W_R - W_{SH} - W_F \quad (9)$$

Or the payload fraction is

$$\frac{W_{PAY}}{W_G} = 1 - \frac{W_{ST}}{W_G} - \frac{W_E}{W_G} - \frac{W_R}{W_G} - \frac{W_{SH}}{W_G} - \frac{W_F}{W_G} \quad (10)$$

Cost Analysis

The cost analysis is a greatly simplified analysis to facilitate parametric study. It does, however, give representative, even if not precise, cost estimates. The particular figure of merit used in the analysis is the cost of carrying cargo expressed in dollars per metric ton-kilometer (dollars/ton-n mi). It is intended that the analysis yield the total cost to the consumer for hauling cargo on the vehicle. It does not include in-port handling. It does account for vehicle utilization and load factor.

Vehicle cost. - The vehicle capital cost is composed of structure cost C_{ST} , engine cost C_E , reactor cost C_R , and shield cost C_{SH} . All costs are in dollars. Any other capital costs must be included in at least one of these four costs. The total cost is given by

$$C_{TOT} = C_{ST} + C_E + C_R + C_{SH} \quad (11)$$

The cost of the structure in dollars is given by

$$C_{ST}(\text{dollars}) = 1000 K_S(\text{dollars/kilogram}) W_{ST}(\text{metric tons}) \quad (12a)$$

$$C_{ST}(\text{dollars}) = 2000 K_S(\text{dollars/pound}) W_{ST}(\text{tons}) \quad (12b)$$

where K_S is the unit structure cost and W_{ST} is the structure weight.

The cost of the engine in dollars is given by

$$C_E(\text{dollars}) = K_E(\text{dollars/kilowatt}) P_S(\text{kilowatts}) \quad (13a)$$

$$C_E(\text{dollars}) = K_E(\text{dollars/horsepower}) P_S(\text{horsepower}) \quad (13b)$$

where K_E is the unit engine cost and P_S is the required shaft power.

The cost of the reactor (exclusive of fuel) in dollars is given by

$$C_R(\text{dollars}) = K_R(\text{dollars/megawatt}) P_{th}(\text{megawatts}) \quad (14)$$

where K_R is the unit reactor cost and P_{th} is the required reactor thermal power.

The shield cost in dollars is given by

$$C_{SH}(\text{dollars}) = 1000 K_{SH}(\text{dollars/kilogram}) W_{SH}(\text{metric tons}) \quad (15a)$$

$$C_{SH}(\text{dollars}) = 2000 K_{SH}(\text{dollars/pound}) W_{SH}(\text{tons}) \quad (15b)$$

where K_{SH} is the unit shield cost and W_{SH} is the shield weight.

Operating cost. - The total operating cost C'_{TOT} is the sum of the following costs expressed in dollars per operating hour:

- (1) Chemical fuel, C'_{FC}
- (2) Nuclear fuel, C'_{FN}
- (3) Crew, C'_{CR}
- (4) Structure depreciation, C'_{ST}
- (5) Machinery depreciation, C'_{E}
- (6) Reactor core depreciation, C'_{R}
- (7) Shield depreciation, C'_{SH}
- (8) Maintenance, C'_{M}
- (9) Interest, C'_{INT}
- (10) Insurance, C'_{INS}
- (11) Profit, C'_{PR}

Fuel cost. - The chemical fuel cost per operating hour C'_{FC} is found from the following expression, where C_{FC} is the cost of chemical fuel:

$$C'_{FC}(\text{dollars/hour}) = C_{FC}(\text{dollars/kilogram}) P_S(\text{kilowatts}) S(\text{kilograms/kilowatt-hour}) \quad (16a)$$

$$C'_{FC}(\text{dollars/hour}) = C_{FC}(\text{dollars/pound}) P_S(\text{horsepower}) S(\text{pounds/hour-horsepower}) \quad (16b)$$

The nuclear fuel cost per operating hour C'_{FN} is given by

$$C'_{FN} = C_{FN} P_{th} \quad (17)$$

where C_{FN} is the cost of nuclear fuel per thermal megawatt-hour produced by fission. The nuclear fuel cost includes nuclear fuel burnup cost, fuel element manufacturing cost, fuel reprocessing and shipping costs, and interest charges on unburned nuclear fuel. It is intended to cover all costs associated with the nuclear fuel cycle. The reactor cost given by equation (14) therefore does not include fuel element costs.

Crew cost. - The cost of the crew per operating hour C'_{CR} is assumed to be constant. In other words, the number of crew numbers is independent of vehicle size and all other variables.

Depreciation costs. - The structure depreciation cost per operating hour C'_{ST} is the hourly depreciation of the value of the structure. The relation used to determine this cost is

$$C'_{ST} = \frac{C_{ST}}{2T_{ST}} \quad (18)$$

where C_{ST} is the structure cost in dollars and T_{ST} is the life of the structure in operating hours. This relation is a crude approximation to the rate at which funds must be set aside so that at the end of life enough funds exist to replace the item in question. It assumes that the interest accrued by the funds set aside for depreciation doubles the actual funds set aside.

Similarly, the machinery depreciation cost C'_E , the reactor depreciation cost C'_R , and the shield depreciation cost C'_{SH} are given by

$$C'_E = \frac{C_E}{2T_E} \quad (19)$$

$$C'_R = \frac{C_R}{2T_R} \quad (20)$$

$$C'_{SH} = \frac{C_{SH}}{2T_{SH}} \quad (21)$$

Maintenance cost. - The maintenance cost of the entire vehicle per operating hour C'_M is assumed to be proportional to the cost of the vehicle. It is given by

$$C'_M = K_M C_{TOT} \quad (22)$$

where K_M is a maintenance cost factor that depends on vehicle type and C_{TOT} is the total vehicle cost in dollars.

Interest cost. - The interest cost per operating hour C'_{INT} is given by

$$C'_{INT} = \frac{K_{INT} C_{TOT}}{8760 U} \quad (23)$$

where K_{INT} is an interest cost factor which is equal to one-half the interest rate, U is the utilization factor that is the fraction of the total hours in a year that the vehicle operates, and 8760 is the total number of hours in a year.

Insurance cost. - The insurance cost per operating hour C'_{INS} is given by

$$C'_{INS} = K_{INS} C_{TOT} \quad (24)$$

where K_{INS} is an insurance cost factor and C_{TOT} is the total vehicle cost in dollars.

Profit cost. - The profit cost per operating hour C'_{PR} is given by

$$C'_{PR} = K_{PR} (C'_{FC} + C'_{FN} + C'_{CR} + C'_{ST} + C'_E + C'_R + C'_{SH} + C'_M + C'_{INT} + C'_{INS}) \quad (25)$$

where K_{PR} is a profit cost factor that is equal to the ratio of cost charged to the customer to the total operating cost without a profit margin. The profit, in other words, is assumed to be a fraction of the actual cost of providing the transportation service.

Total operating cost. - The total operating cost in dollars per operating hour C'_{TOT} is given by

$$C'_{TOT} = C'_{FC} + C'_{FN} + C'_{CR} + C'_{ST} + C'_E + C'_R + C'_{SH} + C'_M + C'_{INT} + C'_{INS} + C'_{PR} \quad (26)$$

The total operating cost (TOC) is given by

$$\text{TOC(dollars/metric ton-kilometer)} = \frac{C'_{\text{TOT}}(\text{dollars/hour})}{pW_{\text{PAY}}(\text{metric tons}) V(\text{kilometers/hour})} \quad (27a)$$

$$\text{TOC(dollars/ton-nautical mile)} = \frac{C'_{\text{TOT}}(\text{dollars/hour})}{pW_{\text{PAY}}(\text{tons}) V(\text{nautical miles/hour})} \quad (27b)$$

where p is the payload factor (ratio of average payload carried to the full payload-carrying capacity of the vehicle).

ASSUMPTIONS

The specific assumptions made and the range for which each assumption was independently investigated are given in this section. It should be recognized that this study is preliminary in nature. Only a few relatively small air-cushion vehicles have ever been build and operated. Because of the lack of experience and knowledge, no very detailed weight-and-cost analysis can be justified or carried out. This study is, therefore, intended to indicate performance potential rather than to make precise weight-and-cost determinations. It is, therefore, useful and necessary to show sensitivity to each assumption by varying it independently over a wide range of values to lend credibility to the analysis.

Performance Assumptions

The assumptions associated with weight, speed, and power are given in this section.

Structure weight. - The ratio of structure to gross weight for ACV's used in the analysis is 0.25. It is typical for ACV's and is assumed to be independent of all vehicle and operating variables for the purpose of this analysis. However, the structure fraction is independently varied from 0.15 to 0.37 for one operating condition to determine sensitivity to structure fraction.

Engine thrust. - The thrust per shaft horsepower of prop-fan (shrouded propeller) engines is shown in figure 7. The data were obtained from reference 8. The thrust per shaft power is plotted as a function of speed. The data correspond to performance anticipated for 1975-1980. Inasmuch as virtually all the thrust is produced by the fan or the propeller rather than by the jet from the shaft engine, the performance shown is inde-

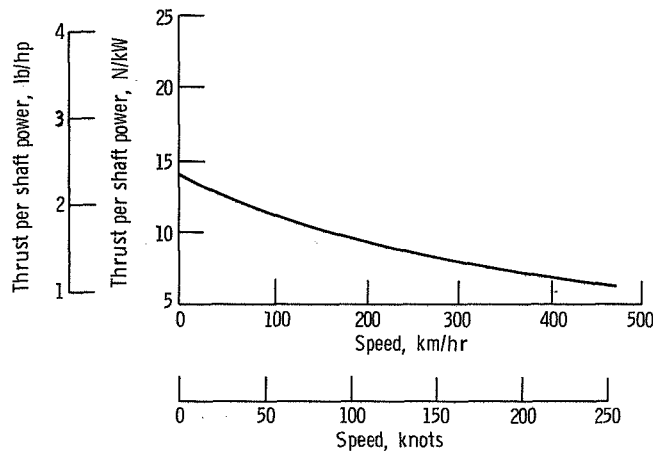


Figure 7. - Thrust per shaft power for prop-fan (shrouded propeller) engine. Chemical and nuclear power. Bypass ratio, 20 (sea level).

pendent of whether the driving engine is nuclear or chemical.

Fuel consumption and efficiency. - The specific fuel consumption S for chemical engines is assumed to be 0.243 kilogram per kilowatt-hour (0.40 (lb/hr)/hp). To determine sensitivity to specific fuel consumption, S is varied from 0.18 to 0.30 kilogram per kilowatt-hour (0.30 to 0.50 (lb/hr)/hp). For nuclear engines the overall thermal efficiency is assumed to be 0.25. It is varied from 0.15 to 0.35 to determine sensitivity to this assumption.

Engine weight. - The weight per shaft power of shrouded propeller engines operating at sea-level conditions is given in figure 8. The data are obtained from reference 8. The specific engine weight is plotted as a function of thrust per shaft power. It is assumed that speed has no effect on this curve. The basic turboshaft engine part of this

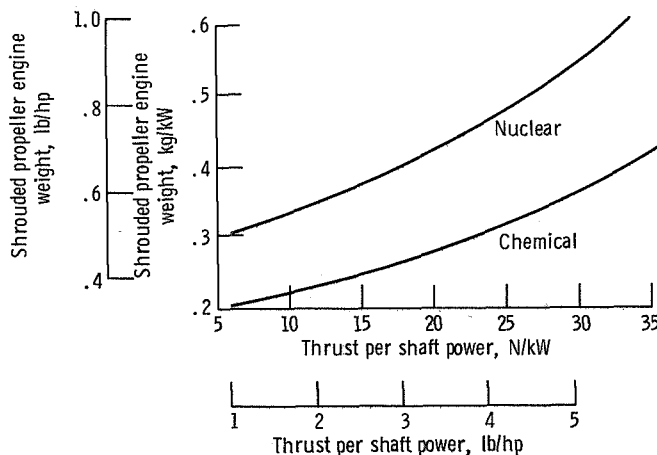


Figure 8. - Shrouded propeller engine weight at sea level.

weight for chemical engines is 0.12 kilogram per kilowatt (0.2 lb/hp). The remainder includes the propeller, shroud, and gears. For nuclear shrouded-propeller engines, the weight was assumed to be 50 percent greater than for chemical engines to account for the heat exchanger and ducting required for nuclear engines, and also to account for the lower turbine inlet temperature that is typical for nuclear engines. These engines are used in the analysis to power the ACV's.

Reactor weight. - The reactor weight density ρ_R required to calculate reactor weight (eq. (5)) is assumed to be 4.8 grams per cubic centimeter (300 lb/ft³). The density is the average of all materials and parts enclosed within the volume formed by the inner diameter of the shield. This density corresponds to a reactor such as described by figure 6. The reactor power density ρ_P is assumed to be 106 watts per cubic centimeter (3.0 MWth/ft³). As in the case of the reactor weight density, the volume used to compute power density includes the entire volume enclosed by the inner diameter of the shield.

Shield weight. - The shield weight is given by equation (7). The shield is a 4π optimized unit shield composed of optimized layers of depleted uranium metal and water. As previously mentioned, it is designed to reduce the dose level at 9.15 meters (30 ft) from the reactor center to 0.25 millirem per hour. At 30.5 meters (100 ft) from the reactor centerline the dose level is 0.025 millirem per hour or less depending on how much structure, cargo, or other material is located between the measuring station and the reactor. The value of the constant B used in equation (7) is 1.0. If a degree of pessimism in the shield weight is desired, any value of B greater than 1.0 may be used. The shield weight is plotted as a function of reactor power in figure 9.

Fuel and range. - The range for chemically powered ACV's is assumed to be 3710, 7420, and 11 130 kilometers (2000, 4000, and 6000 n mi). For nuclear ACV's enough fuel is carried to give an emergency chemical range of 930 kilometers (500 n mi) at design speed. The emergency chemical range of the nuclear vehicles is varied from 0 to 5570 kilometers (0 to 3000 n mi) to determine sensitivity to this parameter.

Cost Assumptions

The assumptions used to calculate specific values of costs are given in this section.

Initial structure cost. - The structure cost is given by equation (12). The values of K_S , assumed for ACV's is \$11 per kilogram (\$5/lb). This assumption is varied from \$2.2 to \$55 per kilogram (\$1 to \$25/lb) to determine sensitivity.

Initial engine cost. - The engine cost is given by equation (13). The value of K_E assumed for this analysis is \$67 per kilowatt (\$50/hp) for chemical engines. For nuclear engines the cost assumed to be 1.25 times the corresponding chemical engine cost. The

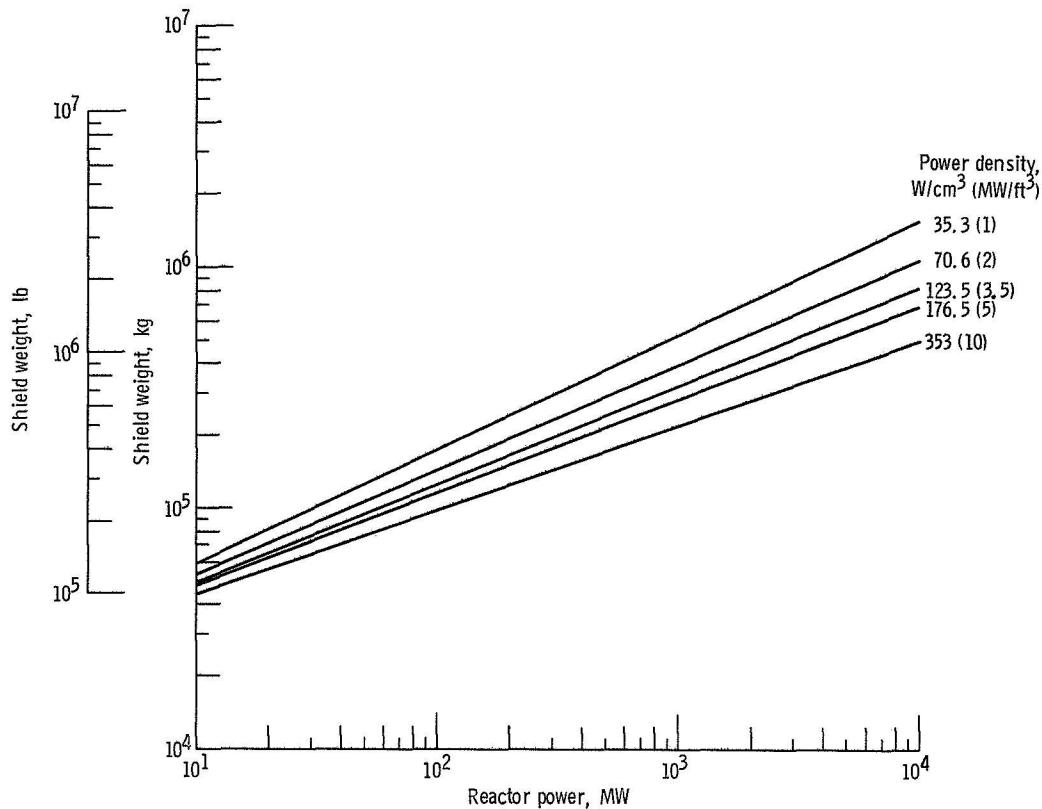


Figure 9. - Shield weight for optimized depleted uranium and water shield. Dose rate at 9.15 meters (30 ft) from reactor centerline, 0.25 millirem per hour. (Spherical shield uniform dose in all 4π directions.)

nuclear engine cost does not include the cost of the reactor shield, or the nuclear fuel. These costs are considered separately.

Initial reactor cost. - The reactor cost is given by equation (14). The value of the constant K_R (dollars/MWth) used for this analysis is 3500. The cost includes only the cost of the reactor vessel, the core structure, in-core control equipment, and other items within the shield. It does not include the fuel element cost. This cost is included in the nuclear fuel cost. The reactor cost is varied from \$1500 to \$10 000 per megawatt thermal to determine sensitivity to this parameter.

Initial shield cost. - The initial shield cost is given by equation (15). The value of K_{SH} used for this analysis is \$11 per kilogram (\$5/lb). This is based on a water and depleted-uranium shield with a stainless-steel containment vessel included in the shield. The shield cost is varied from \$4.4 to \$55 per kilogram (\$2 to \$20/lb) to determine sensitivity.

Fuel cost. - Fuel cost is given by equation (16) for chemically fueled vehicles. The unit fuel cost C_{FC} assumed is \$0.0264 per kilogram (\$0.012/lb). This corresponds to

a cost of about 8 cents per gallon of jet fuel. Nuclear fuel cost is found by use of equation (17). The unit nuclear fuel cost C_{FN} assumed for this analysis is \$0.50 per megawatt thermal per hour. This corresponds to \$12 per gram of uranium-235, or is equivalent to about 1.7 mils per kilowatt-hour of electrical energy for a nuclear electric powerplant with a thermal efficiency of 30 percent. The fuel cost includes manufacturing fuel elements, reprocessing and shipping, interest on unburned fuel, and all other charges normally credited to fuel cost. The value of fuel cost is varied from \$4 to \$24 per gram to indicate sensitivity of the results to fuel cost assumption.

Crew cost. - The crew cost is assumed to be \$250 per operating hour for all vehicles studied in this analysis. This corresponds to the cost of crewing an aircraft like the Boeing 747. This assumption is justified on the basis that an all cargo operation does not require a large crew. It is further assumed that all vehicles are automated to the extent of a large aircraft so that only a small operating crew is required.

Depreciation cost. - The depreciation costs are calculated by equations (18) to (21). The lifetimes assumed for each depreciation cost are as follows:

Structure lifetime, T_{ST} , operating hours	75 000
Machinery lifetime, T_E , operating hours	50 000
Reactor structure lifetime, T_R , operating hours	50 000
Shield lifetime, T_{SH} , operating hours	75 000

Maintenance cost. - Maintenance cost is given by equation (22). The maintenance cost factor K_M is assumed to be 15×10^{-6} . This corresponds to the maintenance cost of Boeing 747 operation (ref. 9). It is assumed for lack of other data that maintenance cost for ACV's will be the same as for aircraft on an initial cost basis. The maintenance cost factor is varied from 4×10^{-6} to 30×10^{-6} to determine sensitivity.

Interest cost. - Interest cost is given by equation (23). The interest cost factor K_{INT} is assumed to be 0.0375, which corresponds to an interest rate of 7.5 percent. The interest rate is varied from 6 to 10 percent in the analysis to show sensitivity.

Insurance cost. - Insurance cost is given by equation (24). The insurance cost factor K_{INS} is assumed to be 3.5. This corresponds to the experience cited above for the Boeing 747 (ref. 9).

Profit cost. - The profit cost is given by equation (25). The profit factor K_{PR} that is assumed for this analysis is 1.20. This assumes that the cost of the transportation service to the customer is 20 percent greater than the actual cost of providing the service. This assumption is varied from 10 to 30 percent to determine the sensitivity of the results to this assumption.

All the assumptions used in this analysis and the range over which each is varied are presented in the following table:

Assumption	Baseline value	Range varied	Equation number
Gross weight, W_G , metric tons; tons	9050; 10 000	900 to 18 100; 1000 to 20 000	(1)
Structure weight fraction, W_{ST}/W_G	0.25	0.15 to 0.37	(2)
Engine weight, W_E/P_S :			
Chemical	See fig. 8	-----	(3)
Nuclear	See fig. 8	-----	(3)
Engine thrust, F/P_S	See fig. 7	-----	(4)
Lift-drag ratio, L/D	See fig. 5	-----	(4)
Reactor weight density, ρ_R , g/cm ³ ; lb/ft ³	4.8; 300	Not varied	(5)
Reactor power density, ρ_P , W/cm ³ ; MW/ft ³	106; 3	35.3 to 353; 1 to 10	(5)
Shield weight factor, B	1.0	Not varied	(7)
Range for chemical ACV, R, km; n mi	3710, 7420, 11 130; 2000, 4000, 6000	-----	(8)
Thermal nuclear efficiency, η	0.25	0.15 to 0.35	(8)
Specific fuel consumption, S, kg/kW-hr; (lb/hr)/hp	0.243; 0.40	0.182 to 0.304; 0.30 to 0.50	(8)
Speed, V, km/hr; knots	185; 100	93 to 315; 50 to 170	(8)
Unit structure cost, K_{ST} , dollars/kg; dollars/lb	11; 5	2.2 to 44; 1 to 20	(12)
Unit engine cost, K_E , dollars/kg; dollars/lb:			
Chemical	110; 50	Not varied	(13)
Nuclear	138; 62.5	Not varied	(13)
Unit reactor cost, K_R , dollars/MWth	3500	1000 to 10 000	(14)
Unit shield cost, K_{SH} , dollars/kg; dollars/lb	11; 5	4.4 to 44; 2 to 20	(15)
Fuel cost			
Chemical, dollars/kg; dollars/lb	0.0264; 0.012	0.0198 to 0.0397; 0.009 to 0.018	(16)
Nuclear, dollars/g	12	4 to 24	(17)
Structure life, ^a T_{ST} , hr	75 000	Not varied	(18)
Engine life, ^a T_E , hr	50 000	Not varied	(19)
Reactor life, T_R , hr	50 000	Not varied	(20)
Shield life, T_{SH} , hr	75 000	Not varied	(21)
Maintenance cost factor, ^a K_M	15×10^{-6}	4×10^{-6} to 30×10^{-6}	(22)
Interest cost factor, ^a K_{INT}	0.075	0.060 to 0.100	(23)
Utilization factor, U	0.5	0.4 to 1.0	(23)
Insurance cost factor, ^a K_{INS}	3.5×10^{-6}	Not varied	(24)
Profit, K_{PR}	20	10 to 30	(25)
Load factor, p	0.6	0.4 to 1.0	(27)
Crew cost, ^a C'_{CR} , dollars/hr	250	Not varied	---

^aBased on Boeing 747 operating experience (ref. 9).

RESULTS

Because of the large volume of results, it is not practical to present all the information obtained in this study. This is especially true of weight and cost breakdowns and performance parameters such as thrust and reactor power. All the results are plotted, therefore, as a function of operating cost only, since this is considered as the most important figure of merit. A few representative results that show performance parameters, and weight and cost breakdowns are presented in tabular form in appendix B.

Calculations of estimated total operating cost as a function of speed were made for 9050-metric-ton (10 000-ton) air-cushion vehicles. The assumptions made in the analysis are intended to reflect attainable performance in the 1980 time period. The correspond-

ing weight breakdowns are also presented to give a feel for the important weight factors. In addition, the sensitivity of performance to most of the assumptions used is presented. The total operating cost is plotted against each varying assumption while the remaining assumptions are fixed. This is done for a 9050-metric-ton (10 000-ton) ACV with a speed of 185 kilometers per hour (100 knots).

The total operating cost that is used in this analysis is to be contrasted to the direct operating cost that is frequently used in transportation studies. The usual direct operating cost does not include, for example, profit which is included in the total operating cost as used herein. It is intended to be the cost charged to the consumer for transportation. It does not, however, include the cost of handling, storing, or shipping the cargo in the originating or destination port. These charges can be major items and must be considered in evaluating a total transportation system. It is recognized that serious attention must be given to the design, operation, and geographical location of port facilities to properly evaluate a total system. A study of this type is beyond the scope of this study.

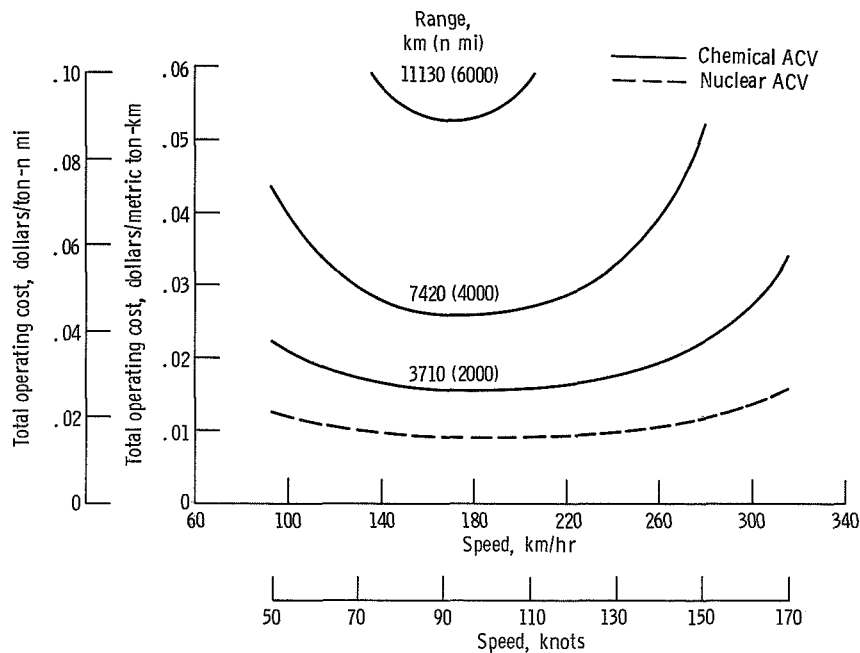


Figure 10. - Total operating cost as function of speed for chemical and nuclear air-cushion vehicles. Gross weight, 9050 metric tons (10 000 tons); structure weight fraction, 0.25; structure cost, \$11 per kilogram (\$5 lb); load factor, 0.6; utilization factor, 0.5; profit, 20 percent.

Total Operating Cost of 9050-Metric-Ton (10 000-Ton) Air-Cushion Vehicles

The total operating cost in dollars per metric ton-kilometer and dollars per ton-nautical mile is plotted as a function of speed for nuclear and chemically powered air-cushion vehicles in figure 10 for a gross weight of 9050 metric tons (10 000 tons). The design ranges for the chemical ACV's are 3710, 7420, and 11 130 kilometers (2000, 4000, and 6000 n mi). The nuclear ACV carries enough emergency chemical fuel to provide a range of 925 kilometers (500 n mi) at design speed.

Both the chemical- and nuclear-powered ACV's have minimum total operating costs at a speed of about 185 kilometers per hour (100 knots). The total operating cost for a transoceanic ACV is about \$0.027 per metric ton-kilometer (\$0.045/ton-n mi) for a range of 7420 kilometers (4000 n mi) and increases to about \$0.054 per metric ton-kilometer (\$0.090/ton-n mi) for a range of 11 130 (6000 n mi). The total operating cost for the nuclear-powered ACV is independent of range. The direct operating cost for a 9050-metric-ton (10 000-ton) nuclear ACV is \$0.009 per metric ton-kilometer (\$0.015/ton-n mi). The nuclear ACV shows a clear advantage over the chemical ACV for ranges of 3710 kilometers (2000 n mi) or greater.

The corresponding weight breakdowns for the nuclear- and chemical-powered 9050-metric-ton (10 000-ton) ACV's are given in figures 11(a) to (d). In the case of the nuclear ACV at 185 kilometers per hour (100 knots), the payload fraction is about 60 percent of the gross weight. This large payload capacity accounts for the superior performance shown by the lowest operating cost. The reactor core, shield, and engines constitute about 9 percent of the gross weight at 185 kilometers per hour (100 knots). The fuel to provide a 925-kilometer (500-n mi) range at cruising speed is about 7 percent of the gross weight for a speed of 185 kilometers per hour (100 knots).

For the chemical-powered ACV, the most notable characteristic is that the fuel predominates the weight at ranges of 7420 kilometers (4000 n mi) or over. For a 7420-kilometer (4000-n mi) range at a speed of 185 kilometers per hour (100 knots), for example, the fuel is about 45 percent of the gross weight. At a 11 130-kilometer (6000-n mi) range the fuel fraction increases to about 60 percent. The engine weight fraction is 2 to 3 percent of the gross weight for the entire range of speeds and ranges.

The operating costs for chemical ACV's given in reference 10 are in good agreement with those calculated in this report. The nuclear ACV operating costs, however, are about a factor of 2 higher than calculated in this study. The difference is largely due to the assumed weight of the nuclear powerplant. The present study indicates that, for 9050-metric-ton (10 000-ton) vehicles, the nuclear propulsion system weighs about 1.82 kilograms per kilowatt (3 lb/hp) compared to the 7.28 kilograms per kilowatt (12 lb/hp) used in reference 10.

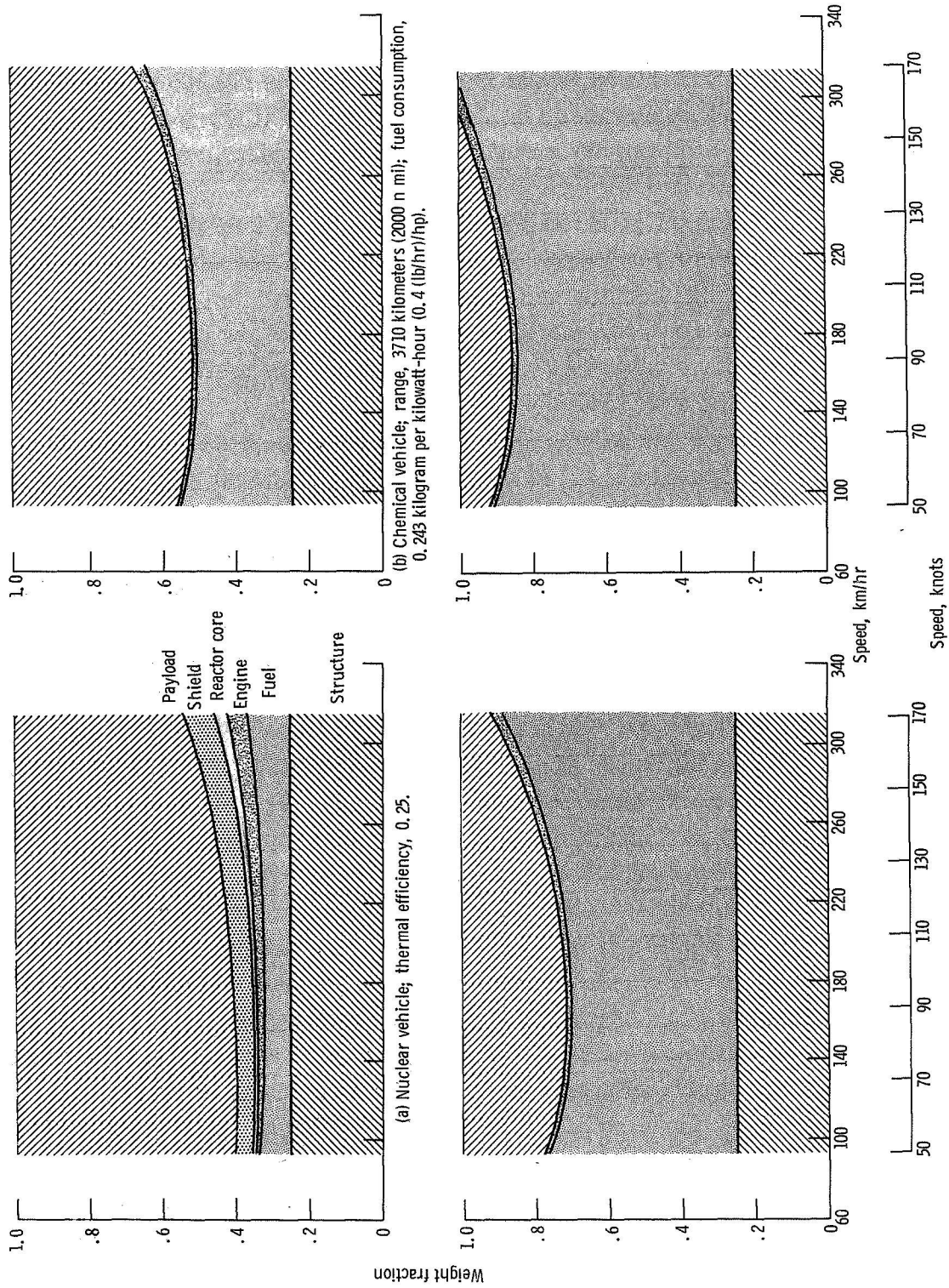


Figure 11. - Weight breakdown as function of speed for nuclear and chemical air-cushion vehicles. Gross weight, 9050 metric tons (10 000 tons); structure weight fraction, 0.25.

A fleet of 1000 nuclear 9050-metric-ton (10 000-ton) ACV's designed to cruise at 185 kilometers per hour (100 knots) theoretically could handle about 7.5 percent of the trans-oceanic commerce predicted for 1980. Whether 7.5 percent of the total trade could be attracted by the possibility of 185-kilometer-per-hour (100-knot) ACV transportation at a rate of \$0.009 per metric ton-kilometer (\$0.015/ton-n mi) is a study that is beyond the scope of this report. Some conjectures can be made based on shipping data presented in reference 2. The reference shows that in 1968 about 11.5 percent of the total U.S. foreign trade was carried by liner. The average value of liner cargo in 1968 was \$0.626 per kilogram (\$0.284/lb). Assuming that the allowable transportation cost is 15 percent of the value of the product shipped gives \$0.097 per kilogram (\$0.043/lb) as allowable shipping cost. At a rate of \$0.09 per metric ton-kilometer (\$0.015/ton-n mi), cargo valued at \$0.626 per kilogram (\$0.284/lb) could then be economically transported a distance of 10 600 kilometers (5700 n mi), which is probably greater than the average trans-oceanic shipping distance.

A 9050-metric-ton (10 000-ton) ACV operating at 185 kilometers per hour (100 knots) can carry 2.5×10^9 metric ton-kilometers (1.5×10^9 ton-n mi) of cargo per year, assuming a utilization factor of 0.5 and load factor of 0.6. It would take a fleet of about 150 to 200 9050-metric-ton (10 000-ton) ACV's to carry the liner cargo that was carried in 1968 in U.S. foreign commerce alone. Consider the facts that U.S. foreign trade amounts to about 25 percent of world transoceanic trade today, that U.S. foreign trade is expanding less rapidly than world trade so that by 1980-1990 U.S. trade will be reduced to about 20 percent of the total, and that world ocean trade will be doubled by 1980. These facts indicate the number of ACV's required to handle world liner-type cargo would be more than 1000. In addition to these factors, consideration must also be given to the possibility that 185-kilometer-per-hour (100-knot) transportation may attract cargo (such as perishables) that heretofore could not be shipped economically.

Sensitivity to Assumptions

In a broad analysis of the kind presented in this study, many assumptions must be made to arrive at specific numbers such as total operating cost. To completely justify each assumption so that no one would question any of them would be at best an unfulfilled dream. Therefore, we have taken the liberty, first of all, to greatly simplify the analysis so as to minimize the number of variables that are considered and, secondly, to select reference values for each of the variables considered. It was the intent to pick what are thought to be reasonable projected values for each of the variables. However, recognizing that there is a great possibility that the reference values may be questioned, almost every variable was independently varied to determine the sensitivity of the results

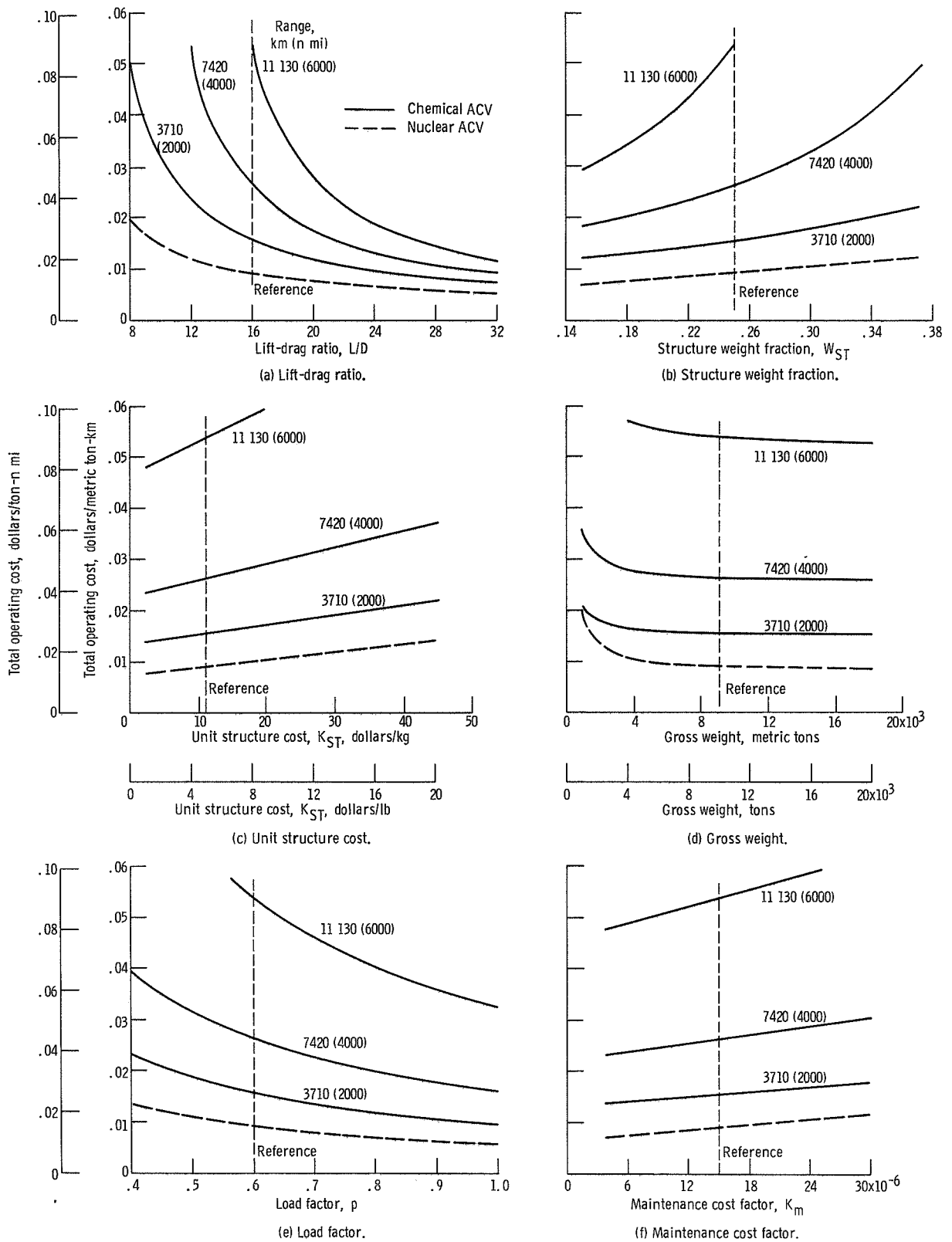
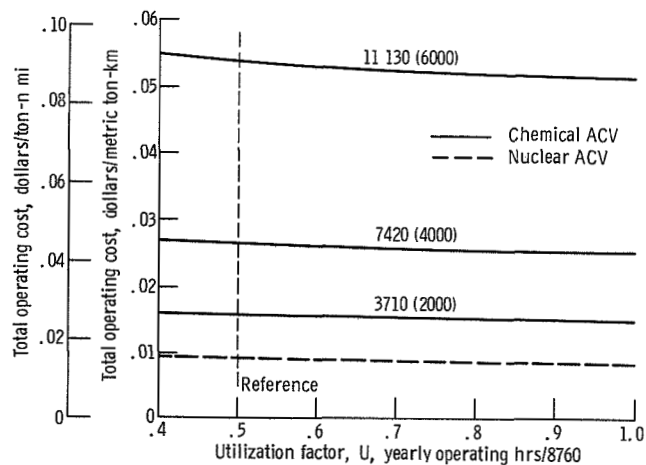
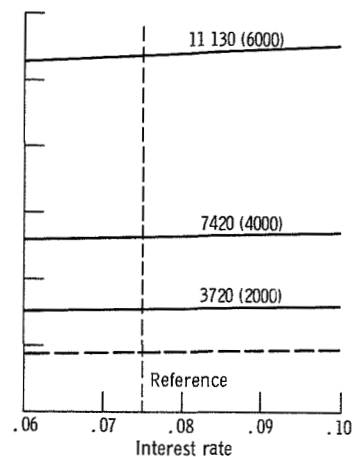


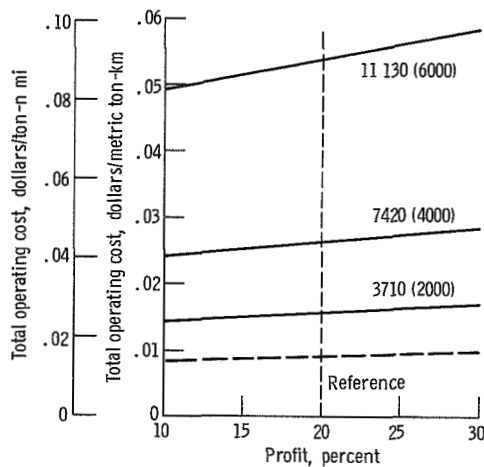
Figure 12. - Effect of variation of major assumptions on total operating cost for nuclear and chemical air-cushion vehicles. Gross weight, 9050 metric tons (10 000 tons).



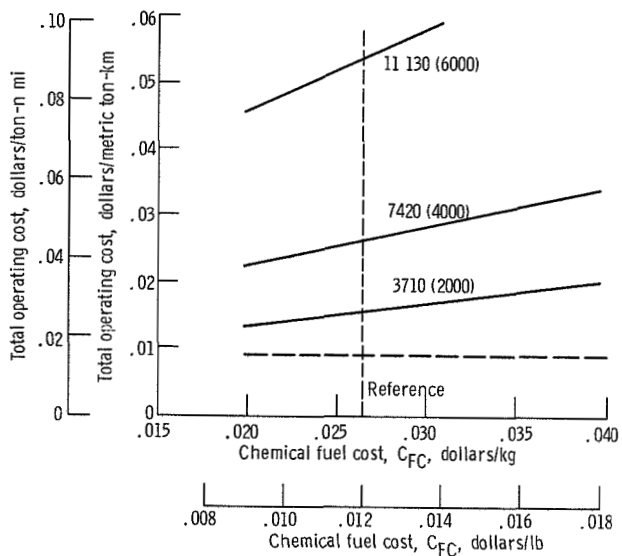
(g) Utilization factor.



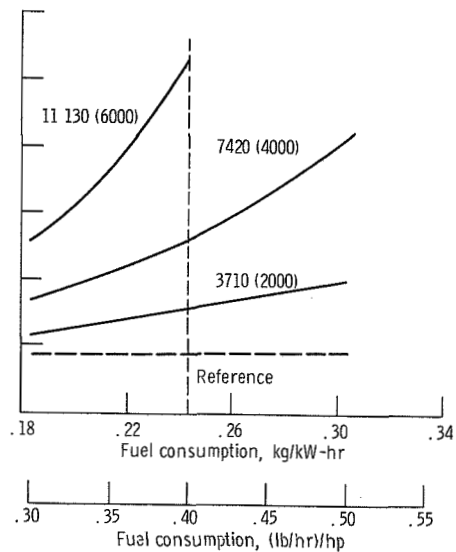
(h) Interest rate.



(i) Profit rate.



(j) Chemical fuel cost.



(k) Fuel consumption.

Figure 12. - Continued.

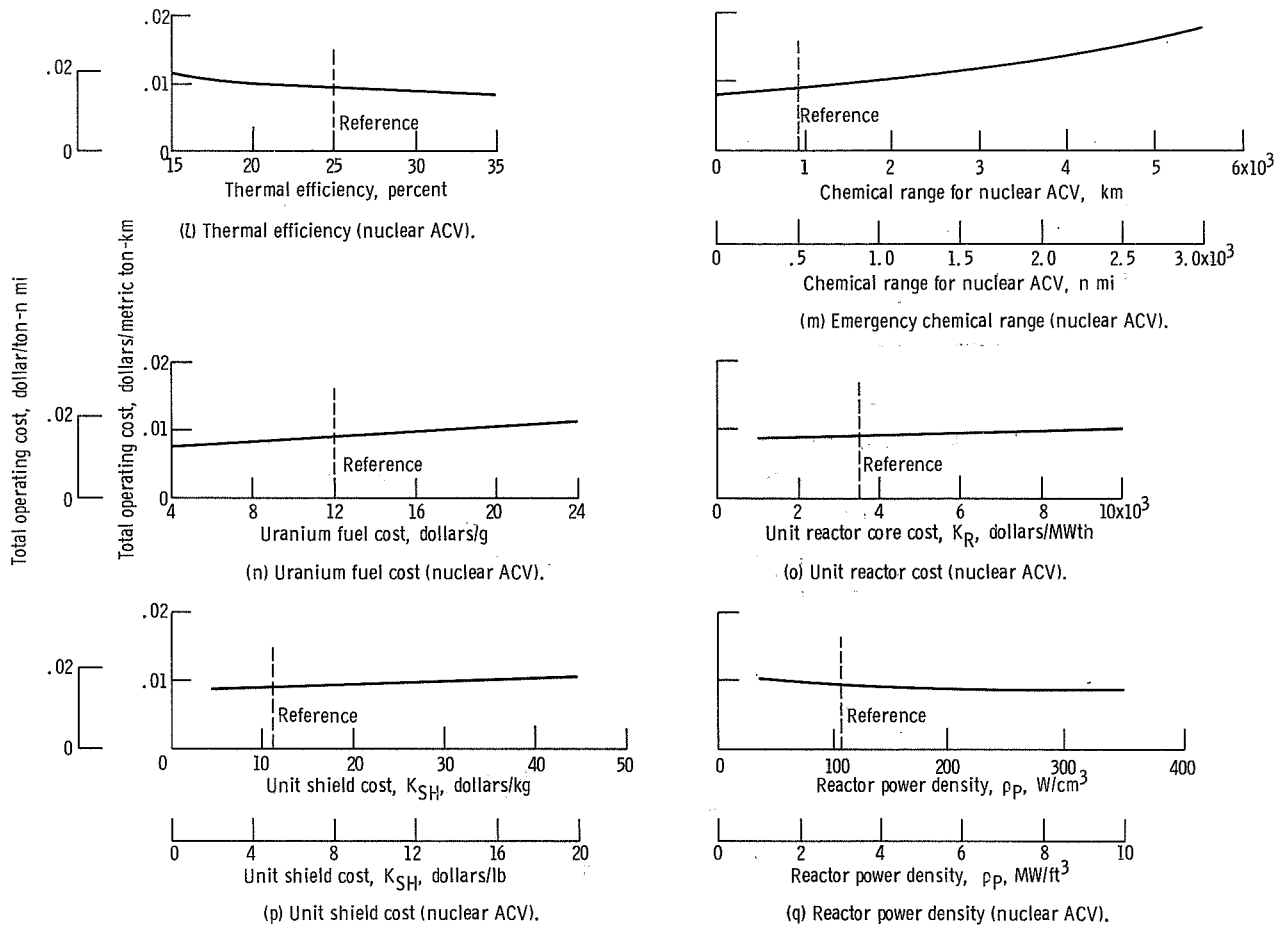


Figure 12. - Concluded.

to the particular assumed value. The effect on total operating cost caused by varying each of the major variables is plotted in the next series of figures.

Figures 12(a) to (q) show the effect of varying each of the following variables on the total operating cost for air-cushion vehicles:

- | | |
|-------------------------------|--|
| (1) Lift-drag ratio | (10) Chemical fuel cost |
| (2) Structure weight fraction | (11) Fuel consumption |
| (3) Structure cost | (12) Thermal efficiency |
| (4) Gross weight | (13) Chemical range for nuclear aircraft |
| (5) Load factor | (14) Uranium fuel cost |
| (6) Maintenance cost factor | (15) Reactor cost |
| (7) Utilization factor | (16) Shield cost |
| (8) Interest rate | (17) Reactor power density |
| (9) Profit rate | |

Examination of figures 12(a) to (q) shows that the variables that could most affect cost performance predictions are lift-drag ratio, structure weight fraction, structure cost, gross weight, load factor, and maintenance cost factor. The effect of changing these variables affects the longer range chemical ACV's severely but does not severely affect nuclear ACV performance. The nuclear vehicle clearly gives much superior performance for ranges of 3710 kilometers (2000 n mi) or greater for all ranges of these six variables.

Reducing L/D from 16 to 12 for the 7420-kilometer (4000-n-mi) chemical ACV increases the total operating cost from \$0.026 to \$0.054 per metric ton-kilometer (\$0.045 to \$0.090/ton-n mi). The total operating cost for the nuclear vehicle would increase to \$0.012 per metric ton-kilometer (\$0.020/ton-n mi) from \$0.009 metric ton-kilometer (\$0.015/ton-n mi).

Increasing the structure weight fraction from 0.25 to 0.35 increases the total operating cost of the 7420-kilometer (4000-n-mi) chemical ACV from \$0.026 per metric ton-kilometer (\$0.045/ton-n mi) to \$0.043 per metric ton-kilometer (\$0.073/ton-n mi). The corresponding change in nuclear ACV operating cost would be from \$0.009 to about \$0.012 per metric ton-kilometer (\$0.015 to about \$0.020/ton-n mi).

The effect of structure cost is not as severe as changing the L/D or the structure weight fraction. The structure cost could be as high as \$31.5 per kilogram (\$14/lb) compared to the reference value of \$11 per kilogram (\$5/lb) and not increase the total operating cost of the nuclear ACV above \$0.012 per metric ton-kilometer (\$0.020/ton-n mi).

Air-cushion vehicle performance is not greatly affected by gross weight until the gross weight is about 3630 metric tons (4000 tons) or less, at which point the effect on operating cost becomes significant.

The penalty of having a load factor of 0.6 instead of 1.0 is such that the total operating cost for nuclear ACV's is increased from about \$0.006 to \$0.009 per metric ton-kilometer (\$0.010 to \$0.015/ton-n mi). The nuclear ACV could operate with a load factor 0.45 before the total operating cost would increase to \$0.012 per metric ton-kilometer (\$0.020/ton-n mi). The percentage change in chemical ACV performance is about the same as for the nuclear ACV.

The maintenance cost for ACV's was assumed to be the same as for large subsonic aircraft (like the Boeing 747) based on the dollar value of the total vehicle. With this assumption the maintenance cost becomes one of the more important cost items as reflected by the sensitivity of the operating cost to changes in maintenance cost. Halving the maintenance cost will reduce the operating cost by about 15 percent for the nuclear ACV and by about 8 percent for the chemical ACV.

Of minor or negligible importance for both chemical and nuclear vehicles are utilization factor, interest rate, and profit rate (figs. 12(g), (h), and (i), respectively).

The chemical fuel cost and specific fuel consumption are fairly important for chemical ACV's, as would be expected. However, reducing fuel cost to \$0.020 per kilogram (\$0.009/lb) from \$0.027 per kilogram (\$0.012/lb) or specific fuel consumption to 0.182 kilogram per kilowatt-hour (0.30 (lb/hr)/hp) from 0.243 kilogram per kilowatt-hour (0.40 (lb/hr)/hp) is not enough to change markedly the relative standing of nuclear and chemical ACV's.

For nuclear ACV's, thermal efficiency and chemical range (figs. 12(l) and (m)) have a noticeable effect on total operating cost but not enough to significantly alter the relative standing between nuclear and chemical ACV's unless the design emergency chemical range for the nuclear ACV goes beyond 5550 kilometers (3000 n mi). The thermal efficiency can be reduced to less than 15 percent and the emergency chemical range can be increased to 2780 kilometers (1500 n mi) before the nuclear ACV total operating cost increases to \$0.012 per metric ton-kilometer (\$0.020/ton-n mi).

The uranium fuel cost, reactor cost, shield cost, and reactor power density (figs. 12(n), (o), (p), and (q), respectively) have relatively minor effects on nuclear ACV performance.

The sensitivity plots indicate that even for wide ranges of the assumed values for the important variables the nuclear ACV is superior to the chemical ACV for transoceanic ranges. The nuclear ACV shows promise of cargo-carrying cost of less than \$0.012 per metric ton-kilometer (\$0.02/ton-n mi) when the important variables were each changed in the pessimistic direction. It would take combined changes of several variables in the pessimistic direction to cause the cost to exceed \$0.012 per metric ton-kilometer (\$0.02/ton-n mi). In order for the ACV to have operating costs of \$0.006 per metric ton-kilometer (\$0.01/ton-n mi) or less, combined improvement in L/D reduction, structure weight, structure cost, and maintenance cost or improvements in utilization would be required. A sample calculation was made for a nuclear ACV that has a L/D of 20 instead of 16, a structure weight fraction of 0.20 instead of 0.25, and a load factor of 0.8 instead of 0.5 with no change in all the other variables. The total operating cost came out to be \$0.0054 per metric ton-kilometer (\$0.009/ton-n mi).

SUMMARY OF RESULTS

Large air-cushion vehicles greater than 3620 metric tons (4000 tons) of gross weight have the potential for hauling transoceanic cargo at rates that are less than \$0.012 per metric ton-kilometer (\$0.02/ton-n mi) at speeds of about 185 kilometers per hour (100 knots). The rate could be as low as \$0.006 per metric ton-kilometer (\$0.010/ton-n mi). A fleet of 1000 of such vehicles could handle about 7.5 percent of the world transoceanic trade projected for 1980. The nuclear-powered ACV using compact lightweight nuclear

reactors shows much superior performance to chemical ACV's for all ranges of 3710 kilometers (2000 n mi) or greater. For ranges of 7420 kilometers (4000 n mi) the chemical ACV total operating cost is three times that for the nuclear ACV (\$0.027 as compared to \$0.009/metric ton-km or \$0.045 as compared to \$0.015/ton-n mi).

Because the nuclear ACV has a very large payload fraction (greater than 50 percent of the gross weight), its performance is not as sensitive as the chemical ACV to the operating and cost assumptions used in the analysis. The reference nuclear ACV at a speed of 185 kilometers per hour (100 knots) has a total operating cost of \$0.009 per metric ton-kilometer (\$0.015/ton-n mi). The L/D could be reduced from 16 to 12 and the operating cost would still be \$0.012 per metric ton-kilometer (\$0.02/ton-n mi) or less. In similar fashion the structure weight fraction could be increased from 0.25 to 0.35; the structure cost increased from \$11 per kilogram (\$5/lb) to \$31 per kilogram (\$14/lb); the load factor reduced from 0.6 to 0.45; the maintenance rate doubled; the thermal efficiency reduced from 0.25 to 0.15; the emergency chemical range increased from 925 kilometers (500 n mi) to 2780 kilometers (1500 n mi). The uranium cost, the reactor core cost, the shield cost, and the reactor power density have a small effect on total operating cost. Within the range of these variables investigated it would be necessary to assume pessimistic values for several variables together in order to increase the total operating cost from \$0.009 per metric ton-kilometer (\$0.015/ton-n mi) to \$0.020 per metric ton-kilometer (\$0.020/ton-n mi).

If the L/D could be increased from 16 to 20, the structure weight decreased from 0.25 to 0.20, and the load factor increased from 0.6 to 0.8, the nuclear ACV could carry cargo at the rate of less than \$0.006 per metric ton-kilometer (\$0.010/ton-n mi), independent of the distance the cargo is carried.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 24, 1971,
126-15.

APPENDIX A

SYMBOLS

B	shield weight constant
C_E	engine cost, dollars
C_{FC}	chemical fuel cost, dollars/kg; dollars/lb
C_{FN}	nuclear fuel cost, dollars/g
C_R	reactor cost, dollars
C_{SH}	shield cost, dollars
C_{ST}	structure cost, dollars
C_{TOT}	total vehicle cost, dollars
C'_{CR}	crew cost per operating hour, dollars/hr
C'_E	machinery depreciation cost per operating hour, dollars/hr
C'_{FN}	nuclear fuel cost per operating hour, dollars/hr
C'_{INS}	insurance cost per operating hour, dollars/hr
C'_{INT}	interest cost per operating hour, dollars/hr
C'_M	maintenance cost per operating hour, dollars/hr
C'_{PR}	profit cost per operating hour, dollars/hr
C'_R	reactor depreciation cost per operating hour, dollars/hr
C'_{SH}	shield depreciation cost per operating hour, dollars/hr
C'_{ST}	structure depreciation cost per operating hour, dollars/hr
F	thrust, N; lb
K_E	specific engine cost, dollars/kW; dollars/hp
K_{INS}	insurance cost factor
K_{INT}	interest cost factor
K_M	maintenance cost factor
K_{PR}	profit cost factor
K_R	specific reactor cost, dollars/MWth
K_{SH}	specific shield cost, dollars/kg; dollars/lb

K_{ST}	specific structure cost, dollars/kg; dollars/lb
L/D	lift-drag ratio
P_S	shaft power, kW; hp
P_{th}	thermal power, MW
p	payload factor
R	range, km; n mi
S	specific fuel consumption, kg/kW-hr; (lb/hr)/hp
T_E	machinery life, hr
T_R	reactor life, hr
T_{SH}	shield life, hr
T_{ST}	structure life, hr
U	utilization factor, yearly operating hours \div 8760
V	speed, km/hr; knots
W_E	engine weight, metric tons; tons
W_F	fuel weight, metric tons; tons
W_G	gross weight, metric tons; tons
W_{PAY}	payload weight, metric tons; tons
W_R	reactor weight, metric tons; tons
W_{SH}	shield weight, metric tons; tons
W_{ST}	structure weight, metric tons; tons
η	overall thermal efficiency
ρ_P	power density of reactor, W/cm ³ , MW/ft ³
ρ_R	reactor average weight density, g/cm ³ ; lb/ft ³

APPENDIX B

WEIGHT AND COST BREAKDOWN

The complete cost breakdown is given for figure 12(d) for gross weights of 1000, 2000, 4000, and 10 000 tons. The program is written in English units. A conversion table is given below for SI units.

(knots)(1.853) = kilometers/hr
(n mi)(1.853) = kilometers
(lb/hr-hp)(0.608) = kg/kw-hr
(hp)(0.745) = kilowatts
(lb(force)/hp)(5.95) = N/kw
(lb(mass)/hp)(0.608) = kg/kw
(tons)(0.907) = metric tons
(dollars/lb)(2.2) = dollars/kilogram
(dollars/hp)(1.34) = dollars/kw
(dollars/ton-n mi)(0.595) = dollars/metric ton-kilometer

SURFACE EFFECT VEHICLE(1,000 TONS)
 PROP FAN(B.B.R.20)
 NUCLEAR POWERPLANT

SPEED	100.0 (KNOTS)
EMERGENCY CHEMICAL RANGE	500.0 (NM)
REACTOR POWER	227.7 MW(THERMAL)
THERMAL EFFICIENCY	0.25
SFC	0.40 (LB/HR-HP)
SHP	76303.1 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.55 (LB/HP)
GROSS WEIGHT	1000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0208
FUEL WEIGHT FRACTION	0.0735
REACTOR CORE WEIGHT FRACTION	0.0114
SHIELD WEIGHT FRACTION	0.2089
PAYLOAD CAPACITY FRACTION	0.4355
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	62.5 (DOLLARS/SHP)
UNIT REACTOR CORE COST	3500.0 (DOLLARS/MW)
UNIT SHIELD COST	5.0 (DOLLARS/LB)
URANIUM COST	0.500 (DOLLARS/MW-HR)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
REACTOR CORE LIFE	50000. (HOURS)
SHIELD LIFE	75000. (HOURS)
STRUCTURE COST	2.500 (MILLIONS OF DOLLARS)
PROPULSION COST	4.769 (MILLIONS OF DOLLARS)
REACTOR STRUCTURE COST	0.797 (MILLIONS OF DOLLARS)
SHIELD COST	2.089 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	10.154 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	114. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	152. (DOLLARS/HR)
STRUCTURE DEPRECIATION	17. (DOLLARS/HR)
MACHINERY DEPRECIATION	48. (DOLLARS/HR)
REACTOR CORE DEPRECIATION	8. (DOLLARS/HR)
SHIELD DEPRECIATION	14. (DOLLARS/HR)
TOTAL DEPRECIATION	86. (DOLLARS/HR)
INSURANCE COST	36. (DOLLARS/HR)
INTEREST COST	87. (DOLLARS/HR)
PROFIT	145. (DOLLARS/HR)
HOURLY COST	870. (DOLLARS/HR)
TOTAL OPERATING COST	0.033291 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(1,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	2000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	76303.1 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	1000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.2630
PAYLOAD CAPACITY FRACTION	0.4731
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	2.500 (MILLIONS OF DOLLARS)
PROPULSION COST	3.815 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	6.315 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	366. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	95. (DOLLARS/HR)
STRUCTURE DEPRECIATION	17. (DOLLARS/HR)
MACHINERY DEPRECIATION	38. (DOLLARS/HR)
TOTAL DEPRECIATION	55. (DOLLARS/HR)
INSURANCE COST	22. (DOLLARS/HR)
INTEREST COST	54. (DOLLARS/HR)
PROFIT	168. (DOLLARS/HR)
HOURLY COST	1010. (DOLLARS/HR)
TOTAL OPERATING COST	0.035594 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(1,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	4000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	76303.1 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	1000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.4569
PAYLOAD CAPACITY FRACTION	0.2792
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	2.500 (MILLIONS OF DOLLARS)
PROPULSION COST	3.815 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	6.315 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	366. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	95. (DOLLARS/HR)
STRUCTURE DEPRECIATION	17. (DOLLARS/HR)
MACHINERY DEPRECIATION	38. (DOLLARS/HR)
TOTAL DEPRECIATION	55. (DOLLARS/HR)
INSURANCE COST	22. (DOLLARS/HR)
INTEREST COST	54. (DOLLARS/HR)
PROFIT	168. (DOLLARS/HR)
HOURLY COST	1010. (DOLLARS/HR)
TOTAL OPERATING COST	0.060302 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(1,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	6000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHp	76303.1 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHp	1.64 (LB/HP)
ENGINE WEIGHT/SHp	0.36 (LB/HP)
GROSS WEIGHT	1000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.5997
PAYLOAD CAPACITY FRACTION	0.1364
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHp)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	2.500 (MILLIONS OF DOLLARS)
PROPULSION COST	3.815 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	6.315 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	366. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	95. (DOLLARS/HR)
STRUCTURE DEPRECIATION	17. (DOLLARS/HR)
MACHINERY DEPRECIATION	38. (DOLLARS/HR)
TOTAL DEPRECIATION	55. (DOLLARS/HR)
INSURANCE COST	22. (DOLLARS/HR)
INTEREST COST	54. (DOLLARS/HR)
PROFIT	168. (DOLLARS/HR)
HOURLY COST	1010. (DOLLARS/HR)
TOTAL OPERATING COST	0.123464 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(2,000 TONS)
 PROP FAN(B.B.R.20)
 NUCLEAR POWERPLANT

SPEED	100.0 (KNOTS)
EMERGENCY CHEMICAL RANGE	500.0 (NM)
REACTOR POWER	455.4 MW(THERMAL)
THERMAL EFFICIENCY	0.25
SFC	0.40 (LB/HR-HP)
SHP	152606.3 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.55 (LB/HP)
GROSS WEIGHT	2000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0208
FUEL WEIGHT FRACTION	0.0735
REACTOR CORE WEIGHT FRACTION	0.0114
SHIELD WEIGHT FRACTION	0.1392
PAYLOAD CAPACITY FRACTION	0.5052
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	62.5 (DOLLARS/SHP)
UNIT REACTOR CORE COST	3500.0 (DOLLARS/MW)
UNIT SHIELD COST	5.0 (DOLLARS/LB)
URANIUM COST	0.500 (DOLLARS/MW-HR)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
REACTOR CORE LIFE	50000. (HOURS)
SHIELD LIFE	75000. (HOURS)
STRUCTURE COST	5.000 (MILLIONS OF DOLLARS)
PROPULSION COST	9.538 (MILLIONS OF DOLLARS)
REACTOR STRUCTURE COST	1.594 (MILLIONS OF DOLLARS)
SHIELD COST	2.783 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	18.915 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	228. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	284. (DOLLARS/HR)
STRUCTURE DEPRECIATION	33. (DOLLARS/HR)
MACHINERY DEPRECIATION	95. (DOLLARS/HR)
REACTOR CORE DEPRECIATION	16. (DOLLARS/HR)
SHIELD DEPRECIATION	19. (DOLLARS/HR)
TOTAL DEPRECIATION	163. (DOLLARS/HR)
INSURANCE COST	66. (DOLLARS/HR)
INTEREST COST	162. (DOLLARS/HR)
PROFIT	231. (DOLLARS/HR)
HOURLY COST	1383. (DOLLARS/HR)
TOTAL OPERATING COST	0.022818 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(2,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	2000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	152606.3 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	2000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.2630
PAYLOAD CAPACITY FRACTION	0.4731
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	5.000 (MILLIONS OF DOLLARS)
PROPULSION COST	7.630 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	12.630 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	733. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	189. (DOLLARS/HR)
STRUCTURE DEPRECIATION	33. (DOLLARS/HR)
MACHINERY DEPRECIATION	76. (DOLLARS/HR)
TOTAL DEPRECIATION	110. (DOLLARS/HR)
INSURANCE COST	44. (DOLLARS/HR)
INTEREST COST	108. (DOLLARS/HR)
PROFIT	287. (DOLLARS/HR)
HOURLY COST	1721. (DOLLARS/HR)
TOTAL OPERATING COST	0.030310 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(2,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	4000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	152606.3 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	2000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.4569
PAYLOAD CAPACITY FRACTION	0.2792
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	5.000 (MILLIONS OF DOLLARS)
PROPULSION COST	7.630 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	12.630 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	733. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	189. (DOLLARS/HR)
STRUCTURE DEPRECIATION	33. (DOLLARS/HR)
MACHINERY DEPRECIATION	76. (DOLLARS/HR)
TOTAL DEPRECIATION	110. (DOLLARS/HR)
INSURANCE COST	44. (DOLLARS/HR)
INTEREST COST	108. (DOLLARS/HR)
PROFIT	287. (DOLLARS/HR)
HOURLY COST	1721. (DOLLARS/HR)
TOTAL OPERATING COST	0.051350 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(2,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	6000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHp	152606.3 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHp	1.64 (LB/HP)
ENGINE WEIGHT/SHp	0.36 (LB/HP)
GROSS WEIGHT	2000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.5997
PAYLOAD CAPACITY FRACTION	0.1364
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHp)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	5.000 (MILLIONS OF DOLLARS)
PROPULSION COST	7.630 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	12.630 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	733. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	189. (DOLLARS/HR)
STRUCTURE DEPRECIATION	33. (DOLLARS/HR)
MACHINERY DEPRECIATION	76. (DOLLARS/HR)
TOTAL DEPRECIATION	110. (DOLLARS/HR)
INSURANCE COST	44. (DOLLARS/HR)
INTEREST COST	108. (DOLLARS/HR)
PROFIT	287. (DOLLARS/HR)
HOURLY COST	1721. (DOLLARS/HR)
TOTAL OPERATING COST	0.105135 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(4,000 TONS)
 PROP FAN(B.B.R.20)
 NUCLEAR POWERPLANT

SPEED	100.0 (KNOTS)
EMERGENCY CHEMICAL RANGE	500.0 (NM)
REACTOR POWER	910.8 MW(THERMAL)
THERMAL EFFICIENCY	0.25
SFC	0.40 (LB/HR-HP)
SHP	305212.6 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.55 (LB/HP)
GROSS WEIGHT	4000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0208
FUEL WEIGHT FRACTION	0.0735
REACTOR CORE WEIGHT FRACTION	0.0114
SHIELD WEIGHT FRACTION	0.0927
PAYLOAD CAPACITY FRACTION	0.5516
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	62.5 (DOLLARS/SHP)
UNIT REACTOR CORE COST	3500.0 (DOLLARS/MW)
UNIT SHIELD COST	5.0 (DOLLARS/LB)
URANIUM COST	0.500 (DOLLARS/MW-HR)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
REACTOR CORE LIFE	50000. (HOURS)
SHIELD LIFE	75000. (HOURS)
STRUCTURE COST	10.000 (MILLIONS OF DOLLARS)
PROPULSION COST	19.076 (MILLIONS OF DOLLARS)
REACTOR STRUCTURE COST	3.188 (MILLIONS OF DOLLARS)
SHIELD COST	3.708 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	35.972 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	455. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	540. (DOLLARS/HR)
STRUCTURE DEPRECIATION	67. (DOLLARS/HR)
MACHINERY DEPRECIATION	191. (DOLLARS/HR)
REACTOR CORE DEPRECIATION	32. (DOLLARS/HR)
SHIELD DEPRECIATION	25. (DOLLARS/HR)
TOTAL DEPRECIATION	314. (DOLLARS/HR)
INSURANCE COST	126. (DOLLARS/HR)
INTEREST COST	308. (DOLLARS/HR)
PROFIT	399. (DOLLARS/HR)
HOURLY COST	2391. (DOLLARS/HR)
TOTAL OPERATING COST	0.018063 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(4,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	2000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	305212.6 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	4000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.2630
PAYLOAD CAPACITY FRACTION	0.4731
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	10.000 (MILLIONS OF DOLLARS)
PROPULSION COST	15.261 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	25.261 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	1465. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	379. (DOLLARS/HR)
STRUCTURE DEPRECIATION	67. (DOLLARS/HR)
MACHINERY DEPRECIATION	153. (DOLLARS/HR)
TOTAL DEPRECIATION	219. (DOLLARS/HR)
INSURANCE COST	88. (DOLLARS/HR)
INTEREST COST	216. (DOLLARS/HR)
PROFIT	524. (DOLLARS/HR)
HOURLY COST	3141. (DOLLARS/HR)
TOTAL OPERATING COST	0.027668 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(4,000 TONS)
 PRDP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	4000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHp	305212.6 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHp	1.64 (LB/HP)
ENGINE WEIGHT/SHp	0.36 (LB/HP)
GROSS WEIGHT	4000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.4569
PAYLOAD CAPACITY FRACTION	0.2792
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHp)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	10.000 (MILLIONS OF DOLLARS)
PROPULSION COST	15.261 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	25.261 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	1465. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	379. (DOLLARS/HR)
STRUCTURE DEPRECIATION	67. (DOLLARS/HR)
MACHINERY DEPRECIATION	153. (DOLLARS/HR)
TOTAL DEPRECIATION	219. (DOLLARS/HR)
INSURANCE COST	88. (DOLLARS/HR)
INTEREST COST	216. (DOLLARS/HR)
PROFIT	524. (DOLLARS/HR)
HOURLY COST	3141. (DOLLARS/HR)
TOTAL OPERATING COST	0.046874 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(4,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	6000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	305212.6 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	4000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.5997
PAYLOAD CAPACITY FRACTION	0.1364
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	10.000 (MILLIONS OF DOLLARS)
PROPULSION COST	15.261 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	25.261 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	1465. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	379. (DOLLARS/HR)
STRUCTURE DEPRECIATION	67. (DOLLARS/HR)
MACHINERY DEPRECIATION	153. (DOLLARS/HR)
TOTAL DEPRECIATION	219. (DOLLARS/HR)
INSURANCE COST	88. (DOLLARS/HR)
INTEREST COST	216. (DOLLARS/HR)
PROFIT	524. (DOLLARS/HR)
HOURLY COST	3141. (DOLLARS/HR)
TOTAL OPERATING COST	0.095970 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(10,000 TONS)

PROP FAN(B.B.R.20)

NUCLEAR POWERPLANT

SPEED	100.0	(KNOTS)
EMERGENCY CHEMICAL RANGE	500.0	(NM)
REACTOR POWER	2276.9	MW(THERMAL)
THERMAL EFFICIENCY	0.25	
SFC	0.40	(LB/HR-HP)
SHP	763031.4	HORSEPOWER
LIFT/DRAG	16.0	
THRUST/SHP	1.64	(LB/HP)
ENGINE WEIGHT/SHP	0.55	(LB/HP)
GROSS WEIGHT	10000.0	(TONS)
STRUCTURE WEIGHT FRACTION	0.2500	
ENGINE WEIGHT FRACTION	0.0208	
FUEL WEIGHT FRACTION	0.0735	
REACTOR CORE WEIGHT FRACTION	0.0114	
SHIELD WEIGHT FRACTION	0.0542	
PAYLOAD CAPACITY FRACTION	0.5901	
UNIT STRUCTURE COST	5.00	(DOLLARS/LB)
UNIT PROPULSION COST	62.5	(DOLLARS/SHP)
UNIT REACTOR CORE COST	3500.0	(DOLLARS/MW)
UNIT SHIELD COST	5.0	(DOLLARS/LB)
URANIUM COST	0.500	(DOLLARS/MW-HR)
PROFIT FRACTION	0.20	
STRUCTURE LIFE	75000.	(HOURS)
MACHINERY LIFE	50000.	(HOURS)
REACTOR CORE LIFE	50000.	(HOURS)
SHIELD LIFE	75000.	(HOURS)
STRUCTURE COST	25.000	(MILLIONS OF DOLLARS)
PROPULSION COST	47.689	(MILLIONS OF DOLLARS)
REACTOR STRUCTURE COST	7.969	(MILLIONS OF DOLLARS)
SHIELD COST	5.420	(MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	86.078	(MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50	
LOAD FACTOR	0.60	
FUEL COST	1138.	(DOLLARS/HR)
CREW COST	250.	(DOLLARS/HR)
MAINTENANCE COST	1291.	(DOLLARS/HR)
STRUCTURE DEPRECIATION	167.	(DOLLARS/HR)
MACHINERY DEPRECIATION	477.	(DOLLARS/HR)
REACTOR CORE DEPRECIATION	80.	(DOLLARS/HR)
SHIELD DEPRECIATION	36.	(DOLLARS/HR)
TOTAL DEPRECIATION	759.	(DOLLARS/HR)
INSURANCE COST	301.	(DOLLARS/HR)
INTEREST COST	737.	(DOLLARS/HR)
PROFIT	895.	(DOLLARS/HR)
HOURLY COST	5373.	(DOLLARS/HR)
TOTAL OPERATING COST	0.015173	DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(10,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	2000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	763031.4 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	10000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.2630
PAYLOAD CAPACITY FRACTION	0.4731
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	25.000 (MILLIONS OF DOLLARS)
PROPULSION COST	38.152 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	63.152 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	3663. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	947. (DOLLARS/HR)
STRUCTURE DEPRECIATION	167. (DOLLARS/HR)
MACHINERY DEPRECIATION	382. (DOLLARS/HR)
TOTAL DEPRECIATION	548. (DOLLARS/HR)
INSURANCE COST	221. (DOLLARS/HR)
INTEREST COST	541. (DOLLARS/HR)
PROFIT	1234. (DOLLARS/HR)
HOURLY COST	7404. (DOLLARS/HR)
TOTAL OPERATING COST	0.026082 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(10,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	4000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	763031.4 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	10000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.4569
PAYLOAD CAPACITY FRACTION	0.2792
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	25.000 (MILLIONS OF DOLLARS)
PROPULSION COST	38.152 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	63.152 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	3663. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	947. (DOLLARS/HR)
STRUCTURE DEPRECIATION	167. (DOLLARS/HR)
MACHINERY DEPRECIATION	382. (DOLLARS/HR)
TOTAL DEPRECIATION	548. (DOLLARS/HR)
INSURANCE COST	221. (DOLLARS/HR)
INTEREST COST	541. (DOLLARS/HR)
PROFIT	1234. (DOLLARS/HR)
HOURLY COST	7404. (DOLLARS/HR)
TOTAL OPERATING COST	0.044188 DOLLARS/TON-NM

SURFACE EFFECT VEHICLE(10,000 TONS)
 PROP FAN(B.B.R.20)
 CHEMICAL POWERPLANT

SPEED	100.0 (KNOTS)
RANGE	6000.0 (NM)
SFC	0.40 (LB/HR-HP)
SHP	763031.4 HORSEPOWER
LIFT/DRAG	16.0
THRUST/SHP	1.64 (LB/HP)
ENGINE WEIGHT/SHP	0.36 (LB/HP)
GROSS WEIGHT	10000.0 (TONS)
STRUCTURE WEIGHT FRACTION	0.2500
ENGINE WEIGHT FRACTION	0.0139
FUEL WEIGHT FRACTION	0.5997
PAYLOAD CAPACITY FRACTION	0.1364
UNIT STRUCTURE COST	5.00 (DOLLARS/LB)
UNIT PROPULSION COST	50.0 (DOLLARS/SHP)
CHEMICAL FUEL COST	0.012 (DOLLARS/LB)
PROFIT FRACTION	0.20
STRUCTURE LIFE	75000. (HOURS)
MACHINERY LIFE	50000. (HOURS)
STRUCTURE COST	25.000 (MILLIONS OF DOLLARS)
PROPULSION COST	38.152 (MILLIONS OF DOLLARS)
TOTAL VEHICLE COST	63.152 (MILLIONS OF DOLLARS)
UTILIZATION OF VEHICLE	0.50
LOAD FACTOR	0.60
FUEL COST	3663. (DOLLARS/HR)
CREW COST	250. (DOLLARS/HR)
MAINTENANCE COST	947. (DOLLARS/HR)
STRUCTURE DEPRECIATION	167. (DOLLARS/HR)
MACHINERY DEPRECIATION	382. (DOLLARS/HR)
TOTAL DEPRECIATION	548. (DOLLARS/HR)
INSURANCE COST	221. (DOLLARS/HR)
INTEREST COST	541. (DOLLARS/HR)
PROFIT	1234. (DOLLARS/HR)
HOURLY COST	7404. (DOLLARS/HR)
TOTAL OPERATING COST	0.090471 DOLLARS/TON-NM

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